THE ACTION OF THE BEATER

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BY

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PREFACE

SOME time ago I was confronted with the problem of designing a beater for handling rag stuff. My particular object was to evolve a design which would handle twice as much stuff as an existing small beater and give double the output without altering the character of the finished stuffs. The complete absence of any theory of the action of the beater immediately made itself felt. No basis existed for establishing a comparison between different beaters. I was, therefore, led to conduct a series of investigations, the results of which are published in the present treatise.

The investigations were undertaken from the physical and mechanical point of view. The chemical and papermaking aspects were only dealt with where it was found essential to include them, for the beater and the beating process have already been described at length elsewhere from the standpoint of papermaking technology. There has, however, always been a marked scarcity of information on the physical side of the problem which has been felt not least by those occupied with the design and construction of beaters.

The complete inaccessibility of the actual beating zone renders it impossible to observe visually what takes place between the roll and the bedplate. It was, therefore, necessary to proceed in the first instance by measuring everything that could be measured. The problem then devolved into discovering in the labyrinth of experimental data the trail of a theory consistent

with the whole of the observed facts. The future alone will show whether this object has been achieved, for in order to establish the theory firmly it must first be tentatively applied to a far larger number of cases than has been practicable up to the present. It is hoped, however, that the present work will be of interest if alone by reason of its having demonstrated that the *beating problem is capable of scientific treatment. In the past doubts as to the possibility of this have not infrequently been expressed.*

I have necessarily been confined to indicating the factors and dimensions which determine the behaviour of the beater, and must leave for the future the collection and co-ordination of the experimental data which are required to produce a numerical basis for design. The experimental results obtained so far are not sufficiently extensive to form a reliable framework for the construction of such a basis. For the present they should be regarded merely as an example of how the theory can be applied to practice.

It will be realised that the beating tests now described are only the first steps towards a comprehensive investigation, and they may, therefore, still appear in some respects to be incomplete. On the other hand, it was necessary to carry out these tests without interfering with the normal work of the paper mill in which they were conducted. They occupied the entire time of an engineer, and it was impossible to repeat them, desirable as repetition sometimes appeared after results had been worked out and omissions thereby discovered. In certain sections of the work there are even considerable gaps, such, for example, as in the determination of the effect of the beating pressure and the consistency on the output of the beater. The analysis of the specific power consumption of the beater and several other

important questions have also unfortunately been unable to receive the comprehensive treatment which would have been so desirable.

The present volume is a translation of the revised edition of my Danish dissertation, entitled "Heltojshollaenderen," I. and II. By revising the original dissertation it has been possible to include reference to the latest investigations on the effect of beating on the character of the stuff, and this has now been inserted in the appropriate portion of the work. The section entitled "The Theory of Beating" has merely been simplified by omitting some of the mathematics in order to make it more readily understandable. In the second part of the book it has been possible to enlarge considerably the chapter on "Tearing Experiments," as in the meantime numerous further experiments have been carried out in this connection. Finally, the conditions governing the formation of fibrages on the edges of the flybars have been carefully investigated. For the reader's convenience a table is appended explaining the meanings of the somewhat numerous mathematical symbols employed.

SIGURD SMITH, Dr. techn.

CHARLOTTENLUND,
DENMARK, *September* 1922.

FOREWORD

IN commending this treatise to technologists for careful and conscientious study, it may be pointed out that, with increasing recognition of the value of research work, such as the author has carried out and brought to successful fruition through the equally difficult task of critical exposition, there are very many who have not passed the stage of pious opinion in regard to science: and especially in the industry of Papermaking the pious opinion only advances very slowly to the conviction that science determines technical progress always, and in its higher flights or deeper probings creates industry.

The beater, as the pivot of the mill, and the beating preparation of the fibrous raw material, as *the* papermaking operation, are recognised as presenting a number of unsolved problems, with the attraction of unrealised margins of advantage both as regards quality, qualities of product in relation to raw material, and costs of production, values of papers in relation to expenditure on account of power, labour, and upkeep of machinery. Hence the long history of invention in improved design of beater, based rather on empirical study and characterised by adaptation or *tâtonnement*, to use the expressive French word.

Contrariwise the present treatise is boldly theoretical and implicitly affirms that the beater and its functions as an operating machine admit of comprehensive

quantitative expression and methodical treatment by the generalised procedure of science.

At this date there are many converts to "theory" as potentially useful in the mill: but there are the unconverted who are antagonised by the discipline of theory, even to active opposition and resentment.

On reflection they will discover that the cause of opposition to "theory" is that they are theorists: they have a philosophy of "practice"! But so has science. In controlling the operations of the beater the personal factors of judgment and experience are much more effective when in turn directed and controlled *by system and method. Science strengthens craftsmanship and in no sense supplants it.*

In illustration of this point the reader may turn to Chapter VI. of the treatise, pp. 77-87, and note how the author applies theory to the discussion of the results of the comparative investigations of previous observers towards the quantitative evaluation of economy and efficiency of beaters in terms of the factors generally recognised. He will find that the theory of the earlier chapters establishes a basis of very practical criticism.

But another fruitful result of the author's work is to give prominence to the consideration of a factor, which, while recognised as operative, has for obvious reasons eluded measurement. This is the fibre attaching itself to the bars and brought under the direct milling action between the bars of the roll and bedplate. For this a simple descriptive word has been found, viz., "Fibrage" or "Bar-fibrage," which has been adopted by the author and translator and already favourably received by the technologists of the industry.

Dr Smith has singled this out from the many factors of the integral result, that is "whole stuff" preparation, as the most direct measure of beater efficiency, not-

withstanding that actually it is only susceptible of indirect measurement.

This is the subject of a later exposition (1922), a paper communicated to the Royal Society of Arts (*Journal of*, 8th December 1922), of which readers are fully aware through the technical literature of the trade and industry.

This treatise claims attention, therefore, on its basis of research work, comprising the records of systematic investigations in the mill: through formulating a main factor as a more direct definition of aim towards improved construction: and lastly through *clearing the way for the more direct investigation of those qualities of "whole stuff" which are developed in the physical-chemical region of phenomena*, that is the unseen or sub-sensible arena of molecular interactions.

The treatise marks a stage of technical progress to which many have contributed by researches which receive the author's appreciative criticism.

In the form of the present translation it will stimulate the scientific-technical development of the papermaking art in English-speaking countries.

C. F. CROSS.

TRANSLATOR'S NOTE

In casually turning over the leaves of this book for the first time, the impression may possibly be produced that it is of more interest to the mathematician than to the papermaker. A little closer study will, however, show that this is not the case. The mathematical treatment of the subject represents the application of a method of strictly logical definition and reasoning necessary to the investigation of the action of the beater: also it will be found that the mathematical processes involved are of the simplest order.

The summary at the end of the book sets out the author's conclusions in non-mathematical terms, and would at once appeal to any reader interested in the main subject. Even if the mathematics be ignored the book on general study will be found to set forth interesting and stimulating matter, with results of numerous tests carried out under mill conditions, recorded and criticised in terms easily understood.

The translator and the papermaking world are indebted to Mr C. F. Cross for the words "fibrage" and "cell." The former is a new word to express a phenomenon newly appreciated in regard to the functions of the beater, and prominently dealt with in the present treatise. "Cell" is an expressive and not unfamiliar word to denote the pockets formed by the spacing of the flybars on the beater roll.

It would have been an easy matter to reduce the weights and measures from the metric system of Dr

Smith's original dissertation to the time-honoured systems of measurement in use here and on the other side of the Atlantic. One of the objects of this book, however, is to assist in establishing the beating problem on a logical, and consequently a scientific, basis. The metric system is common to scientists in every country, and it has, therefore, been thought only fit and proper to adhere to this system in the English translation.

R. M.

LONDON, *March* 1923.

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KEY TO MATHEMATICAL SYMBOLS OCCURRING IN THIS VOLUME

A few symbols employed exclusively in connection with special calculations are not included in the following list :—

Symbol.	Meaning.	Dimension.	Page on which explanation may be found.
B, B'	Width of bedplate - - -	metres	23
C	A coefficient (greater than 1) -	...	148
D	Diameter of beater roll - -	metres	...
F	Beating surface (according to Kirchner) = total surface of contact between flybars and bedplate bars	sq metres	29
G	Rate of travel of stuff round the trough = 1·02 V	kg./sec.	148
K	Aggregate length of all portions of bar edges engaging with one another at any given moment	metres	27
L	Width on face (length) of roll -	metres	...
L_s	Cutting length per second -	metres/sec.	24, 25
$L_s(s_g+s_v)$	Beating surface per second -	sq. metres/sec	28
N	Total power consumption of the beater	horse power	92
N_L	Power consumption measured with the roll raised	,,	92
N_M	Power consumption of beating tackle	,,	91
N_R	Power consumed for rotating the roll in the stuff	,,	91
N_{LP}	Power absorbed in bearing friction, etc., at pressure P		91
N_{LO}	Power absorbed in bearing friction, etc., under zero pressure	,,	92
P	Roll pressure (*i.e.*, effective weight of the roll)	kg.	23, 51
Q	Beater furnish (fibrous material)	kg.	14
S_g, S_v	" Slant " of bars - - -	metres	23
T	Resistance to the rotation of the roll in the stuff (tangential force)	kg.	161

Key to Mathematical Symbols—*contd.*

Symbol.	Meaning.	Dimension.	Page on which explanation may be found.
T_m	Beating time, having regard solely to the shortening effect produced	hours	40
T_n	Beating time, having regard solely to the wetting effect produced	hours	43
U	Submerged perimeter of roll -	metres	147, 158
V	Rate of travel of stuff round the trough (by volume)	litres/sec.	65
a	Interval (clearance) between two consecutive flybars	metres	189
c, c'	Coefficients not dependent on the design of the beater	...	40, 43
d_g, d_l	Pitch of bedplate bars and fly-bars respectively	metres	23
e	Energy consumption for cutting, per metre of cutting length	m.kg./metre	102
f	A coefficient of friction or tearing	...	103
g	Acceleration due to gravity -	metres/sec.	...
i	Number of points of intersection between flybars and bedplate bars at any given moment	...	26
k	Specific shortening performance	kg./metre	47
k'	Specific "wetting" performance	kg./sq. metre	47
m_g, m_l	Number of bedplate bars and flybars respectively	...	...
m	A factor indicating the number of times a fibre has been cut	...	14
n	Revolutions per minute - -	...	...
p	Beating pressure - - -	kg./sq. cm.	39, 51
p_f	Surface pressure according to Kirchner	"	29
p_k	Edge pressure - - -	kg./cm.	27
ς	Productivity of the beater in achieving a given shortening effect	kg./hour	41

Key to Mathematical Symbols—*contd.*

Symbol.	Meaning.	Dimension.	Page on which explanation may be found.
q'	Productivity of the beater in achieving a given wetting effect	kg./hour	44
s_g, s_v	Thickness of bedplate bars and flybars respectively	metres	23, 25
v	Speed of flybars, *i.e.*, peripheral speed of roll	metres/sec.	23
x	Depth of stuff in cells - -	mm.	65
α	Cutting angle - - - -	...	23
α_g, α_v	Angular "slant" of bars -	...	23, 25
β_g, β_v	Widths of fringes of fibrages on bedplate bars and flybars respectively	metres	52
β	An angle - - - - -	...	161
γ	Weight of fibres per cm. length	kg./cm.	14
δ	Number of fibres cut per metre of cutting length	...	38
δ	Weight of square rod fibrage per metre length	grams/metre	184
ϵ	A coefficient - - - - -	...	158
λ	Mean length of fibre - -	...	14
λ_1	Mean length of fibre on commencing to beat	cm.	14
μ	Beating coefficient - - -	...	92, 103
μ	Specific power consumption -	m.kg./sq.dcm	105
ρ	Consistency (based on weight of fibrous material)	kg./litre	192
ϕ	Coefficient of internal friction	kg./sq. metre	157
$\omega, \omega_1, \omega_2, \omega'$	Beating degrees (degrees of wetness)	...	20

The Action of the Beater

INTRODUCTORY

It is a matter of common knowledge among those connected with the art of papermaking that the beating process exercises a very marked influence on the character of the finished sheet of paper. If the stuff has not been properly treated in the beater, the utmost skill in handling it on the paper machine may be unavailing, and with such stuff it will frequently be impossible to produce the required quality of finished sheet. In fact it has become almost proverbial to say in connection with many classes of papers that the sheet "is made in the beater."

Notwithstanding the recognised importance of the beating operation, however, the existing state of knowledge of the principles which it involves is distinctly unsettled. This is pretty clearly evidenced alone by the numerous articles on beating appearing in the technical press which give the impression that the subject is practically inexhaustible.

Some maintain that the most economical beating is obtained by employing thick furnishes, others recommend rapid circulation, while a third school advocates that the beating time should be kept as short as possible.[1] While some claim that with the modern

[1] *Wochenblatt fuer Papierfabrikation*, 1915, p. 1717 (hereinafter referred to as *W.f.P.*).

large beaters it is impossible to achieve the same beating effect as with the old-fashioned small beater,[1] and adduce numerous examples to support their case, others again will contest this view and assert that it is merely necessary to adapt the new beaters to the mill conditions of operation.[2]

One of the chief reasons for the inaccurate arguments so frequently encountered is the extraordinarily large number of factors involved in the beating process. One or other of these may so easily be overlooked or forgotten, and the prospects of agreement between two controversialists thus reduced to zero. No biased and subjective method of examination is likely to lead to a clear understanding of the action of the beater: on the contrary, any reliable theory of the beating operation must be largely based on detailed investigation of all the factors concerned and on the properly co-ordinated numerical results of experimental observations.

Makers of beaters are also far from unanimous as to the principles on which the dimensions of beaters should be determined. Different firms frequently recommend very different dimensions for beaters of the same dry capacity. It will be shown later that the cutting length per second is a most important factor in determining the output of a beater, yet an examination of various makers' lists shows this figure to vary from about 7,300 to 25,000 ft. per second for a 3-cwt. beater, for the same peripheral speed of beater roll. Some makers increase the value of the cutting length per second in approximately the same proportion as the furnish of the beater increases. Others, for example, only increase the cutting length per second in the ratio of 1 : 1·4 when the dry capacity of the beater is increased from 3 cwt. to 12 cwt. Usually

[1] *W.f.P.*, 1915, pp. 1355 and 1494. [2] *W.f.P.*, 1915, p. 1575.

the weight of the roll is not stated, although the relation of this to the number, size, and spacing of the bars is of considerable importance.

It is scarcely surprising that under these conditions papermakers are sometimes sorely disappointed when changing over from one size of beater to another: and not infrequently refuse to depart from a type and size with which they are already familiar. Builders of beaters lack definite data on which to base the relative dimensions of beating tackle--roll and bedplate. If a firm of engine builders is asked to build a steam engine to develop a certain horse power at a given speed and under a given steam pressure, they will have the main dimensions of the engine ready to hand, for these are calculated according to certain definite and proved methods, and the dimensions adopted by different firms will tally very closely with one another. Buying a beater of a given capacity is a different matter. It would appear that makers are under the necessity of dimensioning beating tackle on a somewhat insecurely founded method of estimation.

Turning from papermakers and machine builders to professors one finds a similar absence of agreement on the points in question. If, for example, it were required to design a beater to produce stuff of the same character as an existing beater, but to give double the output, the literature on beating would be found to provide an odd assortment of directions.

The first attempt to lay down definite rules for beater calculations was made by Ferdinand Jagenberg,[1] of

[1] Jagenberg comes from an old papermaking family, and after completing an educational course of studies, himself became a papermaker, turning later to the manufacture of beater rolls and bedplates. The book referred to is a result of his latter activities. It has met with widespread success, and has formed the basis for the writings of the majority of subsequent workers.

Remscheid (a former papermaker). In his little book, "Das Hollaendergeschirr in Briefen an einen Papiermacher," Jagenberg in 1887 attempted to describe the principles on which the beating effect of a beater can be determined.

Later Professor E. Kirchner,[1] of Chemnitz, devoted himself to the subject, and was followed by Strobach,[2] manager of the Olleschau paper mill.

In his book, "Der Hollaender," [3] and afterwards in the *Wochenblatt fuer Papierfabrikation*,[4] Professor Haussner, of Bruenn, publishes some theoretical discussions on the action of the beater. In 1907 Professor Pfarr, of Darmstadt,[5] produced a study of the beater in which he attempted to evolve an expression for the beating output. Finally Clayton Beadle and Henry Stevens have carried out very extensive experiments in connection with the economy of beating, in addition to micro-measurements conducted with a view to ascertaining the effect on the fibre.[6]

Of these investigators, Jagenberg concludes [7] that the main factors which determine beating output are the beating pressure and the number of cuts per second. Kirchner is of opinion that the cutting effect of the bars depends on the cutting length per second, on the beating pressure and on the number of points of intersection between the flybars and bedplate bars.[8]

[1] Various articles in the *W.f.P.* and in Kirchner's treatise, "Das Papier. IV., Ganzstoffe."

[2] *W.f.P.*, 1904, "Hollaendertheorie."

[3] Stuttgart, 1902.

[4] *W.f.P.*, 1908, "Die Zerkleinerungsarbeit im Hollaender."

[5] *W.f.P.*, 1907, "Hollaender und deren Kraftverbrauch."

[6] Clayton Beadle and Stevens, "Chapters on Papermaking," 1908. Vol. v., "Concerning the Theory and Practice of Beating."

[7] "Hollaendergeschirr," 2nd Edition, Remscheid, 1894.

[8] "Das Papier. IV., Ganzstoffe," p. 43.

Haussner, on the other hand, holds that no cutting takes place between the flybars and the bedplate bars, and that the beating action depends entirely on crushing and tearing between the surfaces of the bars.[1]

Strobach [2] regards the cutting effect of the beater as being proportional to the cutting length per second, and the crushing effect as proportional to the product of three factors, viz., the area of the bar surfaces in mutual contact, the roll pressure, and the speed of the flybars. Kirchner,[3] however, confines himself to stating that these three magnitudes, in conjunction with the number of intersections per second between the flybars and bedplate bars, materially affect the tearing action of the beating tackle.

Pfarr [4] supports the view that the beating output is affected by the speed of circulation of the stuff round the trough, but is undecided as to how much importance should be attached to the cutting length per second, nor does he express any definite opinion as to the importance of the product "flybar speed" multiplied by "area of contacting surfaces."

Beadle and Stevens maintain that no cutting takes place if the flybars and bedplate bars are parallel,[5] but only if they form an angle with one another. These authorities also assert that the speed of circulation of the stuff has no effect on the beating output.[6] They consider that, at any rate as far as commoner classes

[1] "Die Zerkleinerungsarbeit im Hollaender."

[2] "Hollaendertheorie," *W.f.P.*, 1904, pp. 758-760 and p. 2155.

[3] "Das Papier. IV., Ganzstoffe," p. 43.

[4] "Hollaender und deren Kraftverbrauch."

[5] Beadle and Stevens, "Theory and Practice of Beating."

[6] *Ibid.* Haussner also opposes the view that the rate of circulation directly affects the beating output.

of papers are concerned, the chief function of the beating tackle is to tease out the fibres.

Thus there is abundant divergence as to the identity of the factors which determine beating output—a divergence which discloses the obscurity surrounding the subject. The majority of writers do, however, agree that this obscurity is largely due to lack of serviceable experimental data.

There are still far too few and too incomplete reports available on beating tests to afford in themselves the basis for a satisfactory explanation of the beating operation.

The object of the present treatise is to throw more light on the conditions which govern the output of whole stuff from the beater. The theoretical methods of investigation adopted are based on observations obtained under mill conditions and on the results of experiment. Incidentally, the various opinions which have just been referred to are subjected to critical examination.

The experiments on which the work has been built up were all carried out with whole stuff. The theory which is developed applies primarily to well-beaten strong sheets prepared from chemical wood pulp and rag half-stuffs. It should, moreover, be remarked that no claim is made for the correctness of the present theory, except in conditions under which the beater is really employed to disintegrate the stuff thoroughly, *i.e.*, as a beater and not simply as a mixer.

Taken as a whole, the present work may be regarded as new, both with regard to its results and to the methods of treatment employed. In dealing with parts of the subject which have been treated so thoroughly by previous workers as to require no further comment,

the necessary reference alone is given.[1] The only portions of this volume which are based to any considerable extent on earlier work, are the section dealing with the effect of beating on the stuff and to a lesser extent the section on the mechanics of the beating tackle.

[1] Thus, for example, with respect to the variation in the area of contacting bar surfaces during a revolution of the beater roll, and also with respect to the conditions under which the stuff leaves the roll.

PART I

METHOD OF OPERATION AND OUTPUT

CHAPTER I

THE EFFECT OF BEATING ON THE CHARACTER OF THE STUFF

GENERALLY speaking, the ideas which prevail as to the effect of beating on the properties of the stuff are not very clear. It is true that every good practical paper-maker can tell whether the stuff in the beater is ready or not by observing it and feeling it. This same person, however, might experience considerable difficulty in defining more closely the physical changes which the stuff has undergone.

The beating process is frequently explained by saying that with thin consistencies and heavy roll pressures the fibres are mostly cut (free beating). With thick consistencies and lower pressures the fibres are treated more gently, being partly torn and partly crushed (wet beating). The latter method results in the splitting of linen and cotton fibres—fibrillation—while wood fibres are merely torn.

Careful examination shows, however, that this explanation will not satisfy all contingencies. If, for example, a piece of spinning paper is examined under the microscope, the fibres will be seen to be present in the sheet in an almost uninjured condition. It is almost impossible to distinguish a difference between the fibres in the sheet and those in the raw material. Nevertheless, the sheet must necessarily have been prepared from very wet beaten stuff in order to acquire

its special characteristics. The above explanation of the beating process is also insufficient to show why a sheet prepared from wet stuff should be thinner and more compact than a sheet made from free stuff, nor does it serve to indicate the reason for stuff becoming freer as its temperature rises. *As the sheet runs over the papermaking machine wire it parts with its water quickly or slowly according to whether it is free or* wet, but this is not a direct logical consequence of the above explanation. The latter, therefore, only covers a portion of the ground, and on the whole is unsatisfactory.

Our immediate object will now be to describe in more detail what takes place in the beater. The description will be based on the experimental data of important authorities, and will deal particularly with the physical changes in the stuff and their influence on its further treatment on the papermaking machine as well as with their effect on the finished sheet.

The Shortening of the Fibres.—The fibres are cut between the edges of the flybars and bedplate bars. The thinner the layer of stuff between the bar edges and the greater the pressure, the more pronounced will be the cutting. A. B. Green [1] has shown that the thinner the consistency of the stuff in the beater, the thinner will be the layer of stuff which finds its way between the flybars and the bedplate bars. He found that with the roll pressure remaining constant, the clearance between the bedplate and flybars is small at thin consistencies and increases as the consistency increases. It might be supposed that no cutting would take place unless the roll were so hard down as to bring the surface of the flybars into actual

[1] A. B. Green, "Management of the Beater Room," *Paper*, 1917, No. 23.

contact with the surface of the bedplate bars, that is to say, unless all the fibres were severed. This is not the case. Even if the roll is not right hard down on the bedplate, but " floats " on the layer of stuff present between the roll and bedplate bars, *actual cutting will nevertheless take place to some extent.*

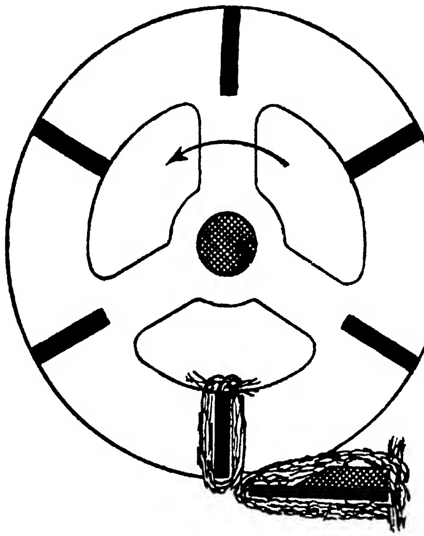


Fig. 1.

A pair of bars is in some respects similar to a pair of shears. The author has found experimentally that even if the shear blades are not pressed closely together, a certain amount of cutting nevertheless takes place. Bundles of hackled hemp were wound round the stationary blade and round one of the revolving blades of a lawn-mower (see Fig. 1). The blades were not

sharp and were adjusted to give a running clearance of less than 1 mm. The mower was then worked so as to pass the one bundle of hemp over the other bundle. Subsequent examination showed that a considerable number of fibres had been cut, the major proportion consisting of those situated nearest to the blades.

Clayton Beadle has examined microscopically the variation in the length of fibres at different stages of the beating process. Providing that the fibres have not been too badly damaged owing to prolonged beating, his method[1] enables the average length of fibre in a beater furnish to be determined at any time during the beating operation.

Let us assume that the average length of fibre has been reduced by beating, to a fraction $\left(\frac{1}{m}\right)$ of its original length. Then on average each fibre will have been cut $(m-1)$ times. Now if the original average length of fibre was λ_1 centimetres at the commencement of beating; and assuming that the fibres weigh γ kilograms per centimetre of length; then if Q is the total weight of fibrous material in the beater, the total number of fibres in the beater on commencing beating must have been $\frac{Q}{\lambda_1\gamma}$. So that if each fibre has been cut $(m-1)$ times, the total number of cuts effected during beating will be $\frac{Q}{\lambda_1\gamma}(m-1)$. This expression, therefore, represents the shortening action which has been effected by beating. At the commencement of beating, when the fibres are comparatively long, the shortening action will progress rapidly; but as the beating proceeds the average length of the

[1] Clayton Beadle, "Chapters on Papermaking," v., chapter xvi.

fibres will diminish more and more slowly. In order to reduce the average length of fibre from λ_1 to $\frac{1}{2}\lambda_1$ $\frac{Q}{\gamma\lambda_1}$ cuts are required. The same number of cuts is also required in order to reduce the average length of fibre from $\frac{1}{2}\lambda_1$ to $\frac{1}{3}\lambda_1$, or, in the general case, from $\frac{1}{n}\lambda_1$ to $\frac{1}{n+1}\lambda_1$. This corresponds exactly with the results of Lehmann's [1] theoretical investigations, and of Clayton Beadle's micro-measurements.[2] Owing to the fact that γ, the weight per centimetre length of fibre, is unknown, the expression $\frac{Q}{\gamma\lambda_1}(m-1)$ can only be employed for the purpose of comparing the shortening effects produced on two furnishes of the same fibrous composition.

Even if the roll is not hard down on the bedplate, as the flybars move round, a drawing-out effect—a sort of carding of the fibres—takes place, which disintegrates the fibre bundles. It must be assumed that the edges of the flybars play a special part in this connection, such that those fibres which, on attempting to enter the roll cells are caught and retained on the bar edges, are torn completely away from the rest of the stuff.

Wet Beating.—As previously remarked, the stuff which makes its way between the working surfaces of the flybars and bedplate bars is subjected to a tearing, pressing (and partly squeezing) action. This results in the formation of fibrillæ from those fibres which can be split lengthwise, while the other fibres are merely teased out and become ragged. As a consequence the interstices between the individual fibres

[1] *W.f.P.*, 1908, p. 1373.
[2] Clayton Beadle, "Chapters on Papermaking," v., p. 151.

become partly filled with fibrillæ and particles of cellulose.

If the beating operation is continued further, cellulose mucilage may be formed, due, according to *Schwalbe,*[1] *to a partial chemical change of the cellulose into hydro- and oxycellulose. The rapidity with which* the mucilage is formed in beating depends on the nature of the raw material. For example, with Mitcherlich sulphite, which has been specially cooked for making imitation parchments, mucilage commences to form after a comparatively short beating treatment. Cotton, on the other hand, requires very prolonged beating before mucilage is formed. The formation of fibrillæ and the teasing out of the fibres, as well as the presence of mucilage, all tend to slow down the rate at which the sheet parts with its water on the wire, owing to the constriction of the pores in the sheet through which the water drains. Although mucilage in itself does not make the sheet felt better, it contributes indirectly to the production of a better felted sheet, because the slower drainage allows the sheet more time for felting.

Another effect of the mechanical treatment of the stuff between the roll and bedplate bar surfaces is to make the fibres softer and more flexible. If, after beating for some time, a handful of stuff is taken up, it will be found to be much softer than on commencing to beat. Provided that this softening can be carried out without injuring the fibres, *i.e.*, without cutting or tearing them, a stuff will be produced which, examined under the microscope, appears similar to the spinning paper stuff referred to previously. The increased softness and flexibility of the fibres also increases their felting properties, and they will distribute themselves on the wire in a thinner and denser layer, thus producing

[1] *W.f.P.*, 1920, p. 1480.

a thinner and less bulky sheet than they would have formed in their original condition. The denser this layer becomes, the smaller will be the interstices between the fibres (pores in the wet sheet), and the more slowly will the water drain away. Thus the greater softness *of the fibres contributes both directly and indirectly to improved felting and so tends to add in a double measure to the strength of the finished sheet.*

Already in 1907 Klemm [1] suggested utilising the softness (plasticity) of half-stuffs as a qualitative basis for comparing them with one another; and constructed his so-called Sedimentation Tester consisting essentially of a glass cylinder with a machine wire bottom. If the water is allowed to drain away from a known weight of half-stuff, the stuff will occupy a certain volume in the glass cylinder. This volume—termed the sedimentation volume—provides a good guide to the character of the stuff, inasmuch as a soft mellow pulp will settle in a thinner, denser layer than one composed of hard stiff fibres. The utility of the results given by the apparatus depends on the assumption that the fibres of the half-stuff are all of the same length and fineness. This is, generally speaking, true when chemical wood pulps are being compared which have been produced from the same class of wood, in which case the magnitude of the sedimentation volume depends solely on the softness (plasticity) of the half-stuff.

The increased flexibility of the fibres may be regarded either as a direct result of the pressure and friction of the beater roll or as an indirect consequence of that action. In the latter case the mechanical treatment causes the fibre to take up water in the walls and cavity and thus to swell. Clayton Beadle [2] is

[1] *W.f.P.*, 1907, pp. 3882, 3986; 1908, p. 1215.
[2] Clayton Beadle, "Chapters on Papermaking," i., p. 104.

also of opinion that the flexibility of the fibre increases with the amount of water which it takes up (hydration). He urges, moreover, that hydration necessitates lengthy beating, so that his view conflicts with the known fact that stuff begins to soften as soon as the roll commences to whip, without necessarily beating. The softening of the fibre can easily be demonstrated on the Schopper-Riegler beating tester; for this apparatus shows that *stuff taken from the beater immediately after whipping has commenced already commences to drain more slowly.*

Under certain conditions the swollen or expanded fibres may become so thick as to double their volume. This increase in volume probably also causes all the small water drainage channels to be reduced in size, thus again reducing the speed of drainage. The "water of hydration" which is absorbed by the fibres cannot be removed by simply applying ordinary pressures. Extraordinarily high pressures would be required to remove it, and the "degree of hydration" of the stuff, therefore, exercises a very important influence on the amount of water which must be evaporated from the sheet by the dryers. When highly hydrated fibres are dried they become, according to Clayton Beadle, stiff and hard. They produce a strong sheet with a good rattle, but the sheet shrinks a great deal in the dryers. Unfortunately very little definite information is available as to the water content of hydrated fibres. Clayton Beadle[1] believes that at ordinary temperatures the amount of water contained is about equal to the dry weight of the fibre, and that on heating, the water content is reduced to approximately 67 per cent. of the dry weight of fibre.

The processes which have just been enumerated—

[1] Clayton Beadle, "Chapters on Papermaking," i., chapter viii.

fibrillation, softening, hydration, possible formation of mucilage (and to some extent the drawing out of the fibres), all combine to produce the changes which are at the root of what the beaterman calls " wet beating."

It is true that the shortening of the fibres also exercises an effect on their capacity for retaining water ; but according to the diagrams [1] published by L. Skark it appears that the effect of shortening is quite slight.

In a general way wetness may, therefore, be defined as the capacity of stuff for parting with its water slowly ; and by wet beating is understood the processes in the beater which induce in the stuff a reluctance to part with its water. The drainage may be compared to the flow of water through capillaries, and follows Poiseuille's law, inasmuch as it depends on the cross-sectional area of the pores, on their length (*i.e.*, on the thickness of the layer of fibres), on the pressure head of water, and on the viscosity of the water.

It is commonly assumed that so-called capillary force or surface tension alone determines the rate of drainage or flow of the water. This view is incorrect ; for the effect of surface tension only commences to be felt when the sheet has drained to the point where the fibres are no longer freely suspended in the water, but rest directly on one another : *i.e.*, in the second stage of the extraction of water from the sheet (on the suction boxes)

Microscopy has furnished a means of determining numerically the shortening effect of beating on the fibres. Fortunately it is now also possible to measure the degree of wetness of stuff and to express this in terms of numbers, by employing a Schopper-Riegler or Skark tester. The former apparatus indicates the wetness and enables a test to be carried out in five

[1] *Der Papierfabrikant*, Festheft, 1910, pp. 53, 54.

minutes with sufficient accuracy for all practical purposes.

The Schopper-Riegler beating tester divides the water into two parts: viz., slow and quick draining. If a perfectly wet stuff were being tested the amount of quick draining water would be nil, while with perfectly free stuff the amount of quick draining water would approximate to 100 per cent. of the total amount of drainable water in the stuff.

If x represent the amount of quick draining water, and if it is assumed that the degree of wetness of the stuff is denoted by the expression $\omega = \frac{100 - x}{100}$, then the degree of wetness (beating degree) of free stuff will be approximately zero, and perfectly wet stuff will possess a degree of wetness equal to 1·0.

The process of transformation of a beater furnish weighing Q kilograms from an initial degree of wetness ω_1 to one of ω_2 may be expressed by the product $Q(\omega_2 - \omega_1)$ which will be regarded as a measure of the effect produced. It should be observed, however, that this is not an absolute measure, but is only applicable in comparing beating processes which have been carried out with identical stuffs. Let it be assumed that the attained effect, $Q(\omega_2 - \omega_1)$, is due partly to tearing, squeezing, and pressing between the bar surfaces, and partly to the whipping action of the flybars.

$Q(\omega_2 - \omega_1)$ may then be put equal to $Q(\omega_2 - \omega') + Q(\omega' - \omega_1)$ where

$Q(\omega_2 - \omega')$ represents the effect due to treatment between the bar surfaces,

and $Q(\omega' - \omega_1)$ represents the effect due to whipping.

It will be shown later how, by means of beater trials, each of these two products can be determined separately.

In order for the stuff to be suitable for making a

given sheet of paper, it must have attained a given degree of wetness and the fibres must have reached a given average length. Thus the two terms ω and $\frac{\lambda_1}{m}$ jointly represent the character of the stuff, or more correctly the character imparted to the stuff by beating.

By proper manipulation, beating can be carried out in such a way that the fibres are shortened without making the stuff wet (beating of stuff for blottings). On the other hand, intense wetness may be sought after in combination with a desire to preserve the length of the fibre (beating for spinning papers) Finally, any character of stuff varying between these two extremes can be obtained.

The Effect of Warmth on the Stuff.—It has been seen how the various effects of the beater on the fibre conduce to forming the characteristics possessed by the finished sheet. There is one other factor which has an important effect on the product of beating, namely temperature. Every papermaker knows that it is impossible to keep stuff wet if prolonged beating has caused it to heat. The reason for this is easy to understand from what has already been said. The viscosity of water decreases with rise in temperature: in fact the decrease is very considerable, even at comparatively low temperatures, such as normally obtain in the beater.[1] For example, if the temperature rises from 5° to 30° C. the viscosity of water will be halved and its rate of drainage will be increased in the same proportion, *i.e.*, it will be doubled. The rate of drainage may, however, sometimes be increased in still greater proportion than that in which the viscosity of

[1] Sigurd Smith, "Ueber den Einfluss der Temperatur auf die Wasserablaufgeschwindigkeit von Zellstoffbrei," *Der Papierfabrikant*, **1919**, p. 1121.

the water is increased. Such additional increase in drainage is probably due to the fact that on heating the fibres become "dehydrated," shrink and become thinner. This causes the interstices between the fibres to become larger, and since they represent capillaries, the water is able to drain away more rapidly than it would if the size of the fibres remained unchanged.

CHAPTER II

THE MECHANICS OF THE BEATING TACKLE

THE following symbols will be employed :—

P = The pressure of the beater roll on the bedplate measured in kilograms.

D = The diameter of the beater roll in metres.

L = Length on face (width) of roll in metres.

m_v = Number of flybars.

m_g = Number of bedplate bars.

s_g and s_v represent the thickness of the bedplate bars and flybars respectively, measured at their working surfaces.

d_g and d_v represent the pitch of the bedplate bars and flybars respectively (see Fig. 2). This is always measured in the direction of rotation of the roll.

B′ = The width of the bedplate in metres (measured in the direction of rotation of the roll).

B = The width of the bedplate + the clearance between two adjacent bedplate bars.

B is therefore equal to $B' + d_g - \frac{s_g}{\cos \alpha_g} = m_g . d_g$.

S_g and S_v represent the "slant" in metres in cases where the bedplate bars or flybars are set obliquely to the axis of the roll (see Fig. 3).

n = Number of revolutions per minute of the roll.

$v = \frac{\pi D n}{60}$ is the peripheral speed of the flybars in metres per second.

α_g and α_v represent the angles which the bedplate bars and flybars respectively make with the axis of the roll.

$\alpha = \alpha_g \pm \alpha_v$ is the cutting angle, *i.e.*, the angle between the flybars and the bedplate bars.

For the purposes of the following mathematical deductions the beating surface between the roll and bedplate will be regarded as a plane surface. This is a slight approximation, but is sufficiently accurate for practical purposes. In reality the beating surface will usually be approximately cylindrical in shape.

For the sake of simplicity it will be assumed that

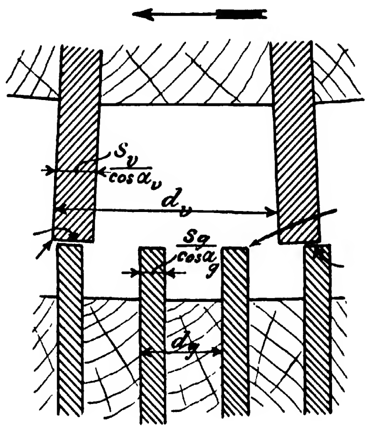


FIG. 2.

all the bedplate bars are straight and of uniform thickness along their length. Mathematical treatment similar to that shown can, however, also be applied to the case of "elbowed" bedplates or to bedplates built up of bars of varying length.

L, represents the cutting length per second, and is measured in metre cuts per second.

A proper conception of the term "cutting length" will be more easily obtained by considering the action

of a shearing machine with parallel shears such as is used for cutting sheet metal, etc.

Referring to Fig. 4, α is the cutting angle between the shear blades, and L is the length of the lower blade which is located at right angles to the direction of motion of the top blade. When the shear blades

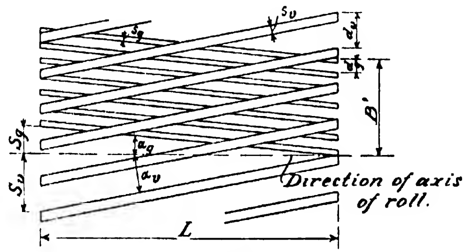


FIG. 3.

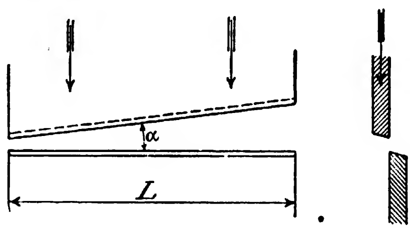


FIG. 4.

are in operation, L is termed the *cutting length*, and it is seen to be independent of the size of the cutting angle. Thus, whether the cutting angle be large or small the cutting length is equal to the projected length of the moving blade measured in the plane perpendicular to its direction of motion.

Similarly, when a flybar passes over the bedplate, whether it be set obliquely or not, the cutting length is

just the same, and is equal to the width on face of the roll. When one flybar passes over the whole bedplate it traverses a cutting length of $m_g.L$ metres. In each second there are $m_v.\frac{n}{60}$ flybars passing over the bedplate, so that the total cutting length per second becomes

$$L_s = m_g.m_v.L.\frac{n}{60} \quad - \quad - \quad - \quad - \quad (1)$$

Let i be the average number of points of intersection between the flybars and the bedplate bars at any moment. This number will vary slightly during the course of a single revolution of the roll; but its mean value can be determined in the following manner (see Fig. 3). Treating the flybars and bedplate bars as straight lines, one flybar will intersect on average :—

$$\frac{S_g \pm S_v}{d_g} = \frac{S_g \pm S_v}{B} . m_g \text{ bedplate bars at a time.}$$

Now since m_v is the total number of the flybars, it follows that at any one moment there will be $\frac{B}{\pi D} . m_v$ flybars located immediately above the bedplate. The aggregate number of points of intersection between flybars and bedplate bars at any moment will, therefore, be

$$i = \frac{S_g \pm S_v}{\pi D} . m_g m_v \quad - \quad - \quad - \quad (2)$$

At every point of intersection the working surfaces of the bars form a parallelogram, two adjacent sides of which are comprised by portions of the working edge of a flybar and bedplate bar respectively. The sum of these two sides is equal to

$$\frac{s_g + s_v}{\sin (a_g \pm a_v)}.$$

Let K be the sum of all the portions of those working bar edges which are simultaneously in engagement with one another (*i.e.*, which at any moment are helping to form the parallelograms). It then follows that

$$K = \frac{S_g \pm S_v}{\pi D} \cdot m_g m_v \cdot \frac{s_g + s_v}{\sin(a_g \pm a_v)}$$

and putting $S_g = L \tan a_g$ and $S_v = L \tan a_v$ the above expression becomes

$$K = \frac{m_g m_v (s_g + s_v) L}{\pi D} \cdot \frac{\tan a_g \pm \tan a_v}{\sin(a_g \pm a_v)}.$$

Now $$\frac{\tan a_g \pm \tan a_v}{\sin(a_g \pm a_v)} = \frac{1}{\cos a_g \cos a_v},$$

so that $$K = \frac{m_g . m_v (s_g + s_v) L}{\pi D \cos a_g \cos a_v} \quad - \quad - \quad - \quad (3)$$

$p_k = \left(\frac{P}{100K}\right)$ represents the edge pressure, *i.e.*, the pressure exercised by the roll per centimetre length of bar edge. For the moment this can, however, not be regarded as anything more than a mathematical symbol; because when the roll is hard down on the bedplate it cannot rest solely on the working edges of the bars, so that p_k is not a magnitude which can be determined by physical measurement. The importance of p_k for purposes of calculation will be explained later.

From equation (3) we have

$$p_k = \frac{\pi D \cos a_g \cos a_v P}{100\, m_g m_v (s_g + s_v) L} \quad - \quad (4)$$

and substituting in equation (3) $\frac{60v}{n}$ for πD, it becomes

$$K = \frac{n . m_g . m_v (s_g + s_v) L}{60v \cos a_g \cos a_v} = \frac{s_g + s_v}{v \cos a_g \cos a_v} \cdot \frac{n . m_g . m_v L}{60}$$

$$= \frac{s_g + s_v}{v . \cos a_g \cos a_v} \cdot L .$$

From this it follows that

$$L_s(s_g + s_v) = Kv \cos \alpha_g \cos \alpha_v \qquad (5)$$

The magnitude $\left(\frac{L_s(s_g + s_v)}{\cos \alpha_g \cos \alpha_v}\right)$ is known as the *beating surface per second of the beater.* If neither the flybars

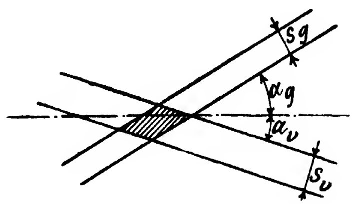


FIG. 5A.

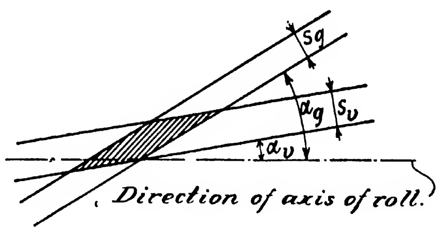


FIG. 5B.

nor the bedplate bars are set obliquely $\cos \alpha_g$ and $\cos \alpha_v$ will be equal to 1. In the general case also $\cos \alpha_g$ and $\cos \alpha_v$ each may be regarded as equal to 1. This is sufficiently accurate for all practical purposes; since the flybars will either be parallel to the axis of the roll or will be set at such a small angle thereto that $\cos \alpha_v$ will approximate to unity. Similarly the bed-

plate bars will usually not be set at a very oblique angle to the axis of the roll, so that $\cos \alpha_g$ can generally be assumed to approximate to unity. This considerably simplifies equation (5), which then becomes

$$L_s(s_g + s_w) = Kv.$$

It will be noted that the dimensions of the beating surface per second are $\left(\frac{\text{metres}^2}{\text{sec.}}\right)$.

It has already been shown that if the roll is touching the bedplate, the working surfaces of both bar systems will engage in a number (i) of small parallelograms. The total surface of contact, measured in square metres, will be denoted by F. The mean value of F can easily be calculated thus :—

The area of each of the (i) parallelograms is

$$\frac{s_g s_w}{\sin(\alpha_g \pm \alpha_w)}$$

(see Figs. 5A and 5B).

Equation (2) gives the number of these parallelograms ; so that in the same way as equation (3) was deduced we have

$$F = \frac{m_g . m_w . s_g . s_w . L}{\pi D \cos \alpha_g \cos \alpha_w} \qquad (6)$$

and in a similar manner to equation (4) we have

$$p_f = \frac{P}{10000\,F} = \frac{\pi D \cos \alpha_g \cos \alpha_w P}{10000\, m_g m_w s_g s_w L} \qquad (7)$$

Substituting in equation (6) $\frac{60v}{n}$ for πD in the same way as equation (5) was obtained, we get

$$L_s s_g s_w = F v \cos \alpha_w \cos \alpha_g \qquad (8)$$

From equations (3) and (6) it follows that

$$\frac{F}{K} = \frac{s_g s_w}{s_g + s_w}$$

and from equations (4) and (7) it follows that

$$\frac{p_f}{p_k} = \frac{s_g + s_w}{100 s_g s_w} \quad - \quad - \quad - \quad - \quad - \quad (9)$$

Equations (1), (2), (6), (7), and (8) have already been deduced by Kirchner in his work, " Das Papier. IV., Ganzstoffe." Equation (7) is the Jagenberg " crushing " formula.

In the foregoing calculations it has been assumed that the bedplate bars are all of uniform thickness and unidirectional. It is, however, quite possible to evolve a similar series of equations to cover conditions where the bedplate bars are not unidirectional, are not all of the same thickness, and are set at varying angles to the axis of the roll (*e.g.*, zigzag and elbowed bedplates).

CHAPTER III

THE THEORY OF BEATING

SOME years ago a theory was advanced that the output of a beater increases in proportion with the speed of circulation of the stuff. This theory was based on the assumption that the oftener each particle of stuff passes between the roll and the bedplate in a given time, the more opportunity it is afforded for being beaten.[1] Careful consideration shows, however, that the theory is illogical and therefore untenable. The speed of circulation is proportional to the quantity of stuff which enters the roll cells. This quantity is a totally different one from the quantity of stuff which is actually subjected to the beating action between the roll and bedplate; and it cannot be assumed that the two stand in any definite relationship to one another.

As far as the author is aware, no experimental data have been adduced to show that output varies with rate of travel. It is quite true that in some cases the output of a beater has been increased by increasing the rate of travel of the stuff; but the increase in output has not risen proportionately with the rate of travel. The author has carried out some tests with four beaters of different sizes and very varying speeds of circulation. According to the theory referred to above, the respective outputs of these four beaters should have been in the ratio of 1 : 32 : 32 : 47; whereas in actual fact the

[1] Pfarr, "Hollaender und deren Kraftverbrauch."

respective outputs were in the ratio of 1 : 2·5 : 2·7 : 4. It therefore follows that the theory must be incorrect.[1]

It will now be attempted to elucidate what factors actually determine the amount of stuff treated between

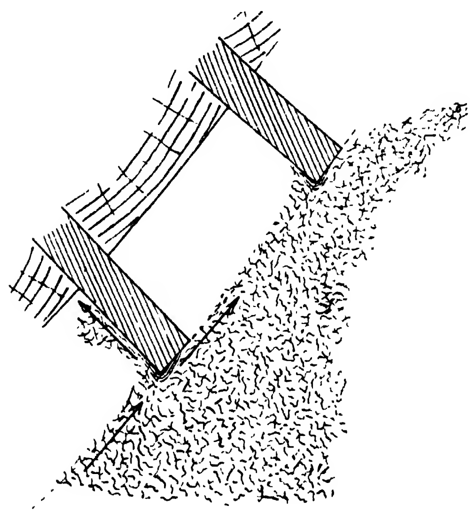


FIG. 6A.

The observer is imagined to be travelling with the flybars. Fig. 6A shows the flybars entering the stuff. The apparent motion of the stuff in relation to the flybars is indicated by arrows. The stream of stuff is cleft by the flybars and a fibrage adheres to the edge of the flybar.

the bars, and to explain how this treatment is effected. It is impossible to observe by eye what goes on, for the action takes place at high speed and in an inaccessible

[1] The experimental data will be found in "Heltojshollaenderen," Table I., p. 30.

spot. It is therefore necessary firstly to propound a theory and then to examine whether the theory fits in with all the known facts.

It is well known to every papermaker that if a bar or rod is drawn through the stuff, fibres will adhere transversely across its edge. *The same thing will take place if the bar is held fast in a stream of stuff in such* a way that the bar cleaves the stream in two, one

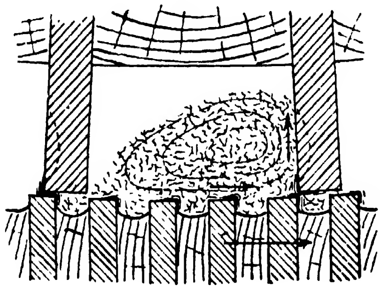


FIG. 6B.

Fig. 6B illustrates two flybars over the bedplate. The observer watches the bedplate pass by in the opposite direction to the motion of the roll, but at the same speed as the latter. In each of the cells there is an eddy of stuff which is kept in motion by the edges of the bedplate bars, thus causing a deposit of stuff (fibrage) to be formed on the edges of the bedplate bars. The relative motions are indicated by arrows.

portion passing along each side of the bar. Applying the same idea to the working edge of a flybar, it will be realised that this also cleaves into two portions a stream of stuff which relatively speaking advances towards it. One portion of the divided stream then moves along the front surface of the flybar and enters the roll cell, while the other portion passes along the working surface of the flybar. Fig. 6A illustrates the

cleavage of the stuff stream. The arrows indicate the motions (relative to the roll). This cleavage has been referred to previously in the literature of beating;[1] but as far as the author is aware the adhesion of the fibre transversely across the edge of the flybar has not been observed or described. To describe the formation of fibres across the bar edge, C. F. Cross suggests the apt term "fibrage."

The motion of the stuff along the front edge of the flybar produces an eddy or rotary motion of the stuff inside the cells. It is highly probable that this eddy action does not cease even when a cell is immediately above the bedplate and the entry of additional stuff thereby prevented. On the contrary, the friction of the stuff against the bedplate will probably tend to assist the eddying. Fig. 6B illustrates such conditions. Here, again, the observer is supposed to be moving round with the flybars, in which case the arrows indicate motions (relative to the roll).

When the cells with their contents of stuff pass over the bedplate it is probable that fibrages also adhere to the edges of the bedplate bars in the same way as they are formed on the flybars. The formation of fibrages on the edges of the bedplate bars is not quite so easy to understand as on the flybars, for it is unlikely that any eddy motions can take place in the spaces between the bedplate bars. Other methods have, therefore, been sought to explain how the fibres come to be deposited on the edges of the bedplate bars. For instance, it might be imagined that the fibres which adhere to the bedplate bars are removed in a simple manner by the flybars; and that each time a flybar passes over a bedplate bar a few of the outermost fibres

[1] Lehmann, *W.f.P.*, 1908, p. 1374; Kirchner, "Das Papier. IV., Ganzstoffe," p. 14.

on the flybar are cut by the edges of the bedplate bars, while a few adhere to the bedplate bar to be crushed and squeezed by the surface of the flybars which follow.

Experiments have been carried out on eighteen beaters in one mill (seven papermaking machines), and examination of the flybars of these beaters appears to have shown that fibrages actually are formed. In this mill the beating action was very gentle, the whipping

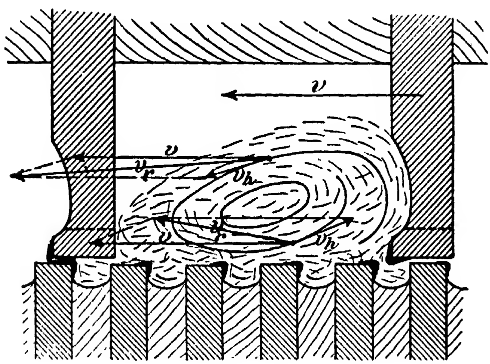


FIG. 7

effect of the roll being chiefly relied on, so that there was no heavy wear on the working surfaces of the bars. The china clay used was somewhat coarse, and it was found that in all the beaters furnished with china clay the front surfaces of the flybars became worn away in the manner illustrated in Fig. 7.

It was satisfactorily demonstrated that this wear was not due to chemical action, but to mechanical action exclusively. The wear only commenced at a little distance (a few millimetres) from the edge of the bar,

the edge itself being protected from wear by the fibrage adhering to it.

In other cases where the roll is run harder on the bedplate (thus increasing the wear due to friction between the flybars and bedplate bars) the flybars usually wear down to the shape indicated by the dotted line.

If the rate of travel in the beater is too slow, or if the flybars are not spaced sufficiently far apart from one another, no appreciable quantity of stuff will be able to enter the cells, and the fibrage on the bar edge will accordingly be too small. In both cases the output of the beater will, therefore, be reduced considerably; and this is probably the reason why so much importance is frequently attached to rapid circulation in the beater. If the flybars are further worn down to such an extent that there is too little room for the eddying "rolls" of stuff in the cells, the rotation of the roll will be checked by the braking action of the stuff against the wooden fillets. If the fillets are removed or trimmed down efficient beating can be resumed again.

Prior to the discovery that stuff is deposited on the bar edges, it had been difficult to see what really causes the fibres to be cut, *i.e.*, by what agency they are made to lie transversely across the bar edges, which is the most favourable position for cutting.[1] It had also not been easy to understand how in fact the stuff penetrated between the surfaces of the flybars and bedplate bars at all unless it was carried by the bar edges or retained by them; for there must be a considerable amount of pressure between the bar surfaces due to the weight of the roll.

It would also be of interest to examine whether the

[1] Kirchner, "Das Papier. IV., Ganzstoffe," p. 49; and Haussner, "Die Zerkleinerungsarbeit im Hollaender," 1908, reprint, p. 4.

stuff does not adhere to the working surfaces of the bars as well as to their edges, as is shown in Fig. 9. This is *a priori* an unlikely hypothesis; nor have the numerous experiments which will be referred to later

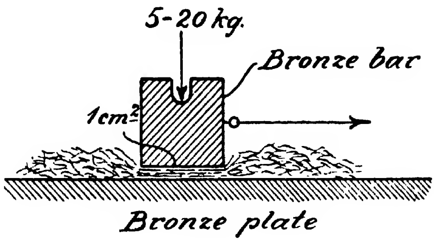


FIG. 8.

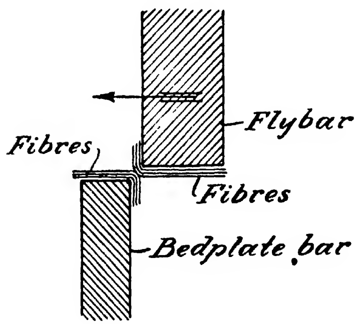


FIG. 9.

been successful in establishing it. At the moment it is only necessary to describe a friction experiment in which a weighted bar was drawn over a layer of stuff resting on a bronze plate.

This experiment showed that when the bar is drawn over the stuff in the direction indicated in Fig. 8, the

stuff is carried along entirely by the edge of the bar, the rearward portion of the stuff always remaining stationary. In the second portion of this book experiments are described in which weighted bars were dragged over layers comprising several sheets of unsized wet crêped serviette papers, similar in character to whole stuff. These sheets were spread out on smooth as well as on ribbed metal surfaces. When smooth surfaces were used, the stuff was carried forward by the edge of the bar; but with ribbed surfaces the sheet stuck fast to the latter, being retained by the edges of the ribs. It will, therefore, be assumed in the following discussions that the stuff is held and carried forward by the bar edges alone; and on this assumption we shall endeavour to calculate the output of the beater.

When a flybar traverses a bedplate bar, a portion of the fibres which lie transversely across the edge of each bar are cut. It is desirable to investigate this cutting action rather more closely. The number of fibres so cut must be proportional to the projected length of the bars on the plane of the roll axis; and this number will be denoted by δ (expressed per metre projected length of bar). Theoretically the amount of the cutting action will not vary, irrespective of whether the angles α_v and α_g are large or small. There are, however, practical limits to the sizes of these angles, as will be seen later.

During the passage of a flybar over the bedplate, the cutting effect is $\delta . m_g . L$, or in each second :—

$$\delta . \frac{n}{60} . m_g . m_v . L = \delta L_s \qquad - \quad - \quad - \quad (10)$$

The value of L_s can be calculated from the dimensions of the beater, and it might be expected that the cutting effect of two beaters each performing the same

cutting process would be proportional to the values of L_s, providing that the fibrages in each beater are well developed, *i.e.*, that they attain their maximum possible size. It is true that in many cases the cutting effect may be proportional to the cutting length if both beaters are working with the same consistency of stuff,[1] and are correctly designed so as to give sufficient circulation and to leave enough room in the roll cells for the stuff to eddy: in fact so as to permit of unrestricted formation of fibrages on the bar edges. On the other hand, practice shows that the cutting effect of a beater can be varied within wide limits. If the consistency is kept constant the cutting effect can be changed by altering the roll pressure; or if the roll pressure is kept constant an alteration to the consistency will alter the cutting effect. Practically speaking, alteration of the consistency and roll pressure [2] are the only means open to the beaterman for regulating the cutting effect.

Although other factors, such as the state of the beater bars, may also come into play, it is only intended here to consider consistency and pressure as affecting cutting effect; for if the bars wear down normally no special importance need be attached to their state of sharpness. It therefore follows that δ, which denotes the number of fibres cut per metre of cutting length, is a function of the consistency and of the actual pressure p (in kilograms per square centimetre) which is exercised by the roll on the fibres (beating pressure). It will be

[1] The size of the fibrages depends on the consistency of stuff in the trough. This is confirmed by Green's experiments from which it appears that when the furnish is thin the layer of stuff between the flybars and bedplate bars is thinner than when the furnish is thick.

[2] Strictly speaking it is the *beating* pressure which directly affects the cutting action. This is explained below. The beating pressure is largely governed by the edge pressure, and to that extent is dependent on the *roll* pressure, *i.e.*, on the effective weight of the roll.

shown later that this pressure varies during the beating process, as it is dependent on the length of the fibres. The value of δ will, therefore, also not remain constant throughout the beating process, but will alter as the beating progresses. Let Δ represent the mean value of δ taken over the entire beating time.

If it is desired to achieve a certain definite cutting effect with two beaters under comparison, the time required in each case must thus be inversely proportional to the value of $\Delta . L_s$. Let T_m denote the number of hours which are required to beat Q kilograms of stuff in a beater until the average length of fibre in the furnish has been reduced to $\frac{\lambda_1}{m}$. We then have

$$\frac{Q(m-1)}{\gamma\lambda_1} = \Delta . L_s . 3600 . T_m .$$

Both sides of this equation express the total cutting effect (*i.e.*, the aggregate number of fibre cuts) during the whole of the beating time; and by putting 3,600 $\gamma\Delta = c$, we have

$$\frac{Q(m-1)}{\lambda_1} = c . L_s . T_m \qquad \text{(10a)}$$

where the coefficient c includes all factors dependent on the nature and preparation of the fibres (such as diameter, weight, and divisibility) and on the roll pressure and the consistency. It should not be forgotten that the coefficient c obviously depends also on the mean value Δ; that is to say, c is governed by the initial and the final state of the stuff, and will, therefore, vary for different beating processes. On the other hand, c is independent of the design of the beater or of the beating tackle (providing that the formation of fibrages can proceed unhindered). It is, therefore, to be expected that the value of c will remain the same if

any given beating process is repeated in different beaters using the same consistency and roll pressure, and if it is assumed that the pressure and consistency do not vary during the beating processes under comparison.

The output capacity of a beater is the number of kilograms of stuff which it will beat to readiness in an hour. (This definition corresponds to those laid down by other writers, such as Kirchner and Pfarr.) If a beaterman is asked to say when he considers the stuff to be ready he may reply that beating is finished when the stuff has become short enough or when it is sufficiently wet. Both these qualities are, of course, important, and if the stuff has been shortened in the proper manner it should also be of approximately the desired degree of wetness; while conversely if the stuff is beaten wet enough it should also be sufficiently short. It is difficult to say whether the beaterman's judgment as to the stuff being short enough actually corresponds exactly to the attainment of a definite mean length of fibre; but for the present this will be assumed to be the case, and the productivity of a beater may, therefore, be stated as the *number of kilograms of stuff which it will beat per hour to a given shortness*. It is denoted by $q = \frac{Q}{T_m}$, and if this value is substituted in equation (10*a*) we get

$$q\frac{(m-1)}{\lambda_1} = c\mathrm{L}_s \qquad \text{(10}b\text{)}$$

The tearing and crushing action on the stuff (wet beating effect) will now be examined a little more closely, commencing again by a consideration of the fibrages adhering to the bar edges. Every time a flybar passes over a bedplate bar, quantities of stuff which are

proportional to $\dfrac{L}{\cos a_g}$ and $\dfrac{L}{\cos a_v}$ respectively are propelled through distances $\dfrac{s_v}{\cos a_v}$ and $\dfrac{s_g}{\cos a_g}$ respectively, through the action of the working surfaces of the opposing bars. The result of this alone would be to produce a tearing action which is proportional to

$$\frac{L}{\cos a_g} \cdot \frac{s_v}{\cos a_v} + \frac{L}{\cos a_v} \cdot \frac{s_g}{\cos a_g} = \frac{L}{\cos a_g \cos a_v}(s_g + s_v).$$

In point of fact, what actually happens is not quite so simple. It must frequently occur, for example, that one fibrage carries away a number of fibres belonging to another fibrage. Again, as will be shown later, the tearing effect is not caused by the surface of a fibrage carried on one bar being abraded against the metallic surface of the engaging bar. It is much more likely that at some point on the carried fibrage a cleavage surface is formed, such that one part of the fibrage moves continuously with the bar, while the other portion is held back by the engaging stationary bar. This produces internal friction within the fibrage, but no appreciable friction between fibre and metal.

Notwithstanding the fact that the actual process is not quite simple, the above equation for the tearing action is probably applicable. It would then follow, that for one complete revolution of the roll the tearing action can be expressed by

$$\frac{L.m_g.m_v}{\cos a_g \cos a_v}(s_g + s_v)$$

and the tearing action per second is then proportional to

$$\frac{n}{60} \cdot \frac{L.m_g.m_v}{\cos a_g \cos a_v}(s_g + s_v) = \frac{L_s}{\cos a_g \cos a_v}(s_g + s_v) \quad (11)$$

This quantity can be calculated direct from the *dimensions of the beater; and one would expect to find that* the wet beating effects of two different beaters, each performing the same beating process, would be in the ratio of the respective values of expression (11). Practical experience, however, as well as measurements with the Schopper-Riegler beating tester, show that other influences besides the design of the beater have an effect on the rapidity with which the stuff becomes wet. As with the cutting of the fibres, the beaterman's chief means of controlling the wetness of the stuff are the consistency and the roll pressure, and these factors must, therefore, be taken into account. The wetness may also be affected by other factors, such as heat, the addition of viscose, size, or other materials; but in order to avoid unnecessary complication, it will be assumed that the character of the beaten stuff is controlled by the consistency and the pressure alone.

In order to obtain an expression for the " wetting " effect of the beater, the quantity (11) must, therefore, be multiplied by a coefficient c' which is a function of the consistency and of the actual pressure p of the roll on the fibres. Supposing a change of wetness of $\omega_2 - \omega'$ is required to be produced in a furnish of Q kilograms of stuff, then the amount of time required to carry out this work must be inversely proportional to

$$c' \frac{L_s}{\cos \alpha_g \cos \alpha_w}(s_g + s_w).$$

If T_w is the beating time in hours required to accomplish this effect, then

$$Q(\omega_2 - \omega') = c' \frac{L_s}{\cos \alpha_g \cos \alpha_w}(s_g + s_w)T_w \qquad (11a)$$

As explained above, c' is dependent on the consistency, on the pressure exercised on the fibres, and there-

fore indirectly on the nature and preparation of the stuff; but not on the design of the beater or beating tackle. It is, therefore, to be anticipated that one and the same value will be found for c', if the *same* beating process is carried out with the same consistency and beating pressure in two different beaters. It will be noted that c', being dependent on the initial condition ω' and the final condition ω_2 of the stuff, will, therefore, possess different values for different beating processes.

$q' = \frac{Q}{T_w}$ may be termed the productivity of the beater per hour in altering the stuff from an initial wetness ω' to a final wetness ω_2. Substituting in equation (11*a*) we have

$$q'(\omega_2 - \omega') = c' \frac{L_s}{\cos \alpha_r \cos \alpha_g}(s_g + s_v) \qquad (11b)$$

Equations (10*b*) and (11*b*) have thus been developed from theoretical hypotheses by mathematical methods. It can only be determined by practical experiment and measurement whether the hypotheses are correct; and the practical application of these equations will, therefore, be dealt with later.

Before proceeding to discuss the meaning of the equations which have been developed, it is proposed briefly to examine what would be the result supposing the stuff were carried and held fast by the working *surfaces* of the bars instead of their edges, and so treated between the roll and the bedplate. In that case the quantity of stuff taken up by each flybar would be $\delta'' s_v$ per metre length of flybar; while each metre length of bedplate bar would take up $\delta'' s_g$ stuff. On a flybar passing over a bedplate bar, the tearing or crushing effect of each bar would then be proportional

to the product of the amount of stuff on the bar multiplied by the distance traversed, *i.e.*, the combined effect of the two bars would be

$$\frac{L}{\cos a_v} \cdot \delta'' s_v \cdot \frac{s_g}{\cos a_g} + \frac{L}{\cos a_g} \delta'' s_g \cdot \frac{s_v}{\cos a_v}.$$

If the same method of calculation is applied as was used in connection with the fibrages adhering to the bar edges, the following equation will be obtained :—

$$q'(\omega_2 - \omega') = c'' \frac{L_s}{\cos a_g \cos a_v} s_g \cdot s_v,$$

or with the assistance of equation (8) :—

$$q'(\omega_2 - \omega') = c'' \mathrm{F}.v.$$

This equation is of interest, inasmuch as it appears to show that the wet beating effect is proportional to F.*v*. The equation would, therefore, appear to confirm the hitherto widely held view that the product F.*v* governs the "wetting" output capacity of a beater. In point of fact, however, this view is not really confirmed, because there is no reason for assuming that the working surfaces of the bars carry or hold the stuff. Kirchner, in his book, "Das Papier. IV., Ganzstoffe," more than once examines whether the wetting output capacity of a beater is proportional to F.*v*; but no practical proof of this has been adduced. (Under very special conditions in which the fibres are so long as to extend from the bar edges right along the working surfaces so as to cover the latter (*e.g.*, in beating half-stuff), the value of F.*v* does probably exercise a determining influence on output.)

Where the bedplate bars are straight (*i.e.*, not elbowed) the angles a_v and a_g will usually be so small that no appreciable error will be introduced by taking

the cosines of these angles as equal to 1. The equations are then greatly simplified and become

$$\left.\begin{array}{ll} & q'(\omega_2 - \omega') = c'L_s(s_g + s_v) \\ \text{or} & q'(\omega_2 - \omega') = c'.K.v \end{array}\right\} \quad - \quad - \quad - \quad (11c)$$

while from p. 41

$$q\frac{(m-1)}{\lambda_1} = cL_s \quad - \quad - \quad - \quad - \quad (10b)$$

If it is desired to produce beaten stuff of a given character, m, ω_2, then it will be necessary so to select the consistency and pressure that the stuff is of the desired wetness at the moment of attaining the requisite shortness; that is to say, when $T_m = T_w$. This makes $q = q'$, and equation (11*c*) divided by equation (10*b*) then becomes

$$\frac{\lambda_1(\omega_2 - \omega')}{m-1} = \frac{c'}{c}(s_g + s_v) \quad - \quad - \quad - \quad (12c)$$

The left-hand side of this equation is the expression for the character of stuff attained; and it will be remarked that the cutting length per second does not affect its value. The character of the finished stuff is thus determined exclusively by the consistency, the pressure, and the sum of the thickness of the flybars and bedplate bars. (For a given beating process the coefficients c and c' depend on the pressure and consistency.) It therefore follows that any beater is capable of being adapted to a wide range of beating processes; for with the same flybars and bedplate bars it is possible merely by varying the consistency and pressure to obtain very different beating effects. Equation (12*c*) shows, however, that with a given thickness of bars $s_v + s_g$, the production of a given character of stuff is conditional on the pressure and consistency being variable between sufficiently wide limits to enable the correct ratio between c and c' to be secured. In order to be able to utilise this equation, c and c' must be

determined as functions of the pressure (p) and consistency for the given beating process. But how can (p), which is the actual pressure on the fibres, be ascertained in practice? No really accurate method of doing this has yet been discovered. The pressure on the fibres can only be determined if it is known precisely *how the fibres are distributed between the surfaces of the flybars and bedplate bars. It will, however,* be shown later that some guide as to the value of p can be obtained by putting $p = \eta . p_k$, and thus expressing it as a function of the edge pressure. The coefficients c and c' for a given beating process can then be regarded as functions of the edge pressure p_k and of the consistency. These functions are best represented by means of curves; but before going on to describe how such curves can be plotted experimentally, the foregoing equations will be reduced to somewhat simpler form.

In view of the fact that c and c', as previously shown, are dependent on the beating process (and consequently on the initial and final states of the stuff) the equations can be so framed that the terms involving the length of fibre and degree of wetness are simplified. In other words, if we put

$$\frac{\lambda_1 . c}{m - 1} = k \text{ and } \frac{c'}{\omega_2 - \omega'} = k'$$

equations (10*b*) and (11*c*) then become

$$q = k . L_s \qquad (10d)$$

and

$$q' = k' L_s (s_{k'} + s_v) \qquad (11d)$$

In dealing with the above simplified expressions it must be remembered that the values of k and k' are dependent on the beating process under investigation, *i.e.*, on the nature of the stuff, its initial condition (λ_1, ω'), and its final condition $\left(\frac{\lambda_1}{m}, \omega_2\right)$. For any given

beating process k and k' depend on the edge pressure p_k and the consistency.

Equation (12c) thus becomes

$$k = k'(s_g + s_r) \quad - \quad - \quad - \quad - \quad (12d)$$

From this form of the equations it is seen that k represents the number of kilograms of stuff which will be reduced to the required length in one hour by a cutting length of one metre per second : k is, therefore, the specific shortening performance for the particular beating process $\left(\text{shortening the fibre from an initial length } \lambda_1 \text{ to a length } \frac{\lambda_1}{m}\right)$. Similarly k' represents the number of kilograms of stuff which will be reduced to the observed degree of wetness in one hour by one square metre of working surface per second : k' is, therefore, known as the specific "wetting" performance for the particular beating process (increasing the wetness from ω' to ω_2).

It will be remarked that this final form of the equations enables them to be employed even if the degree of shortening of the stuff and the increase in wetness have not been determined numerically ; that is to say, if the state of the stuff, instead of being expressed numerically, is defined by the beaterman as being "short enough" or "wet enough." In that case it will not be possible to ignore the influence of whipping, and the difference $\omega_2 - \omega'$ must, therefore, be replaced by the difference $\omega_2 - \omega_1$, so that

$$\frac{c'}{\omega_2 - \omega_1} = k'.$$

The equations in their final form (10d, 11d, and 12d) can be used frequently in practice, because the effect

of whipping is nearly always slight and need not be determined separately.

It will now be indicated how the coefficients k and k' (or c and c') can be found experimentally. Let us assume that for a given beating process, for example for beating a certain sheet of writings from bleached sulphite, the character of the half-stuff is given by λ_1 and ω_1, while the character of the beaten whole stuff is given by $\frac{\lambda_1}{m}$ and ω_2. It will further be assumed that (by a method to be described later) we can ascertain what proportion of the final wetness is due to whipping, so that the value of ω' can be determined. The values of L_s and of $L_s(s_g + s_v)$ can be calculated from the dimensions of the beating tackle.

A number of tests is made at various pressures and consistencies to determine the respective quantities (q) of stuff which will be shortened to the stipulated length per hour of beating time. For this particular purpose the beating time T_m is reckoned as being the time required to attain the given shortness without reference to wetness. The values of c are then calculated from equation (10b) and those of k from equation (10d).

By means of similar tests at various pressures and consistencies, the values of q' and T_w are determined (the latter without reference to the shortness of the stuff). Values for c' and k' can then be found from equations (11c) and (11d) respectively.

We will now assume that curves representing the values of k and k' (or c and c') have been drawn, and that it is required to design beating tackle suitable for carrying out this particular beating process, the output of the beater to be q kilograms per hour. Equation (10d) or (10b) gives the total cutting length per second (L_s) of the beating tackle, and from

equation (12*d*) or (12*c*) the sum of the necessary thicknesses of flybars and bedplate bars can be determined. The dimensions of the beating tackle are thus completely defined by our original expression for L_s.

It is presupposed that a definite consistency has been decided on and that an advantageous edge pressure has been selected. (The consistency will depend on the shape of the beater trough and the slope of its floor.)

The converse problem of finding what output a given beater should be capable of in carrying out a given beating process may be approached in the following way: it is found from equation (10*d*) or (10*b*) what number of kilograms (q) of stuff per hour will be shortened to the required degree with a certain pressure (p) and a certain consistency. Equation (11*d*) or (11*c*) will then give the corresponding value for q'. Should q happen to be equal to q' the output of the beater for the particular beating process is given. If q' is less than q it follows that with the assumed pressure and consistency, the required degree of wetness cannot be obtained with that beater without shortening the fibres too much. If, on the other hand, q' is greater than q, the beater, under the given conditions, will make the stuff too wet. By making trials with various corresponding values of k and k' (or c and c') it is possible to ascertain whether the required character of stuff can be obtained at all with the selected beating tackle. If this should be impossible, it would become necessary to alter the widths of the bars in order to obtain the desired beating effect.

CHAPTER IV

THE BEATING PRESSURE

IN order to confirm by means of beating tests the correctness of the theory which has been evolved, it is first necessary to examine the influence of roll pressure (p) and consistency. It is clear that the pressure which governs the beating process is that pressure which acts on the stuff located between the surfaces of the flybars and bedplate bars. This pressure we have denoted by p (kilograms per square centimetre), and strictly speaking it is termed the beating pressure in order to distinguish it from P which is the downward force exercised by the roll in virtue of its weight. The question arises as to how this beating pressure can be calculated if the roll pressure P is known. If the total surface of contact between the flybars and bedplate bars (represented by F square metres) were covered with stuff, then the beating pressure could be found from the expression $p = \frac{P}{10000.F}$. In the previous chapter, however, it was shown to be incorrect to assume that the beating surface is entirely covered with stuff under all circumstances. As a corollary to the assumption that the stuff is retained exclusively on the edges of the bars, it follows that any adhesion to the working surface of a bar will be in the form of an outcrop or fringe. The width of this fringe will probably depend on the capacity

of the stuff for felting, and particularly on the length of the fibre.

If a pocket knife is dragged through the stuff, it is possible to estimate the length of the fibres by observing those which adhere to the blade. Similarly, *in the case of the beater, the fringe will be wide or narrow according as the fibre is long or short.* Very little is known as to the actual width of the fringe. It has already been seen that the fibrage is able to protect from wear 2 mm. of the front surface of the flybar; and one is tempted to assume that the actual width of the fringe in the beaters in question was about this

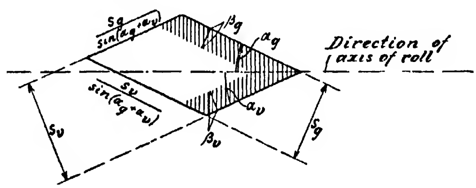


FIG. 10.

amount. The width of fringe measured in metres will be denoted by β.

The surface of contact between a flybar and bedplate bar will now be considered. If there is no stuff between these then the surface of contact will be a parallelogram, of which two adjacent sides are formed by portions of the working bar edges. One of these sides is formed by the bedplate bar and the other by the flybar. In Fig. 10 the fringes of stuff are indicated by shaded lines drawn in the direction of rotation of the roll (perpendicularly to the axis of the roll), that is to say, in the direction in which the fibres themselves tend to lie across the edges of the bars.

The lengths of the sides of the parallelogram are

$$\frac{s_g}{\sin(\alpha_g \pm \alpha_v)} \text{ and } \frac{s_v}{\sin(\alpha_g \pm \alpha_v)}.$$

The width of the fringes of stuff, measured at right angles to the sides of the parallelogram, is β metres. *The area of the stuff-covered portion of the parallelogram at this one point of intersection between flybar and bedplate bar is, therefore,*

$$f = \frac{s_g\beta_v + s_v\beta_g}{\sin(\alpha_g \pm \alpha_v)} - \frac{\beta_g.\beta_v}{(\sin \alpha_g \pm \alpha_v)} = \frac{s_g\beta_v + s_v\beta_g - \beta_g\beta_v}{\sin(\alpha_g \pm \alpha_v)}.$$

It will be assumed that all the bedplate bars are of the same width and lie at the same angle to the axis of the roll. The number of points of intersection between bedplate bars and flybars has already been given as i. There are therefore i parallelograms similar to the one just dealt with. The total area of stuff which undergoes pressure between the roll and the bedplate is, therefore,

$$i.f = \frac{m_g m_v}{\pi D}(S_g \pm S_v) \cdot \frac{s_g\beta_v + s_v\beta_g - \beta_g\beta_v}{\sin(\alpha_g \pm \alpha_v)}$$

$$= \frac{m_g.m_v.L}{\pi D} \cdot \frac{\tan \alpha_g \pm \tan \alpha_v}{\sin(\alpha_g \pm \alpha_v)}(s_g\beta_v + s_v\beta_g - \beta_g\beta_v)$$

$$= \frac{m_g.m_v.L}{\pi D} \cdot \frac{s_g\beta_v + s_v\beta_g - \beta_g\beta_v}{\cos \alpha_g \cos \alpha_v} \qquad (13)$$

One square centimetre of stuff is, therefore, subjected to a pressure of p kilograms, where

$$p = \frac{P}{10000\, i.f.} = \frac{P.\pi.D \cos \alpha_v \cos \alpha_g}{10000\, m_g.m_v L(s_g\beta_v + s_v\beta_g - \beta_g\beta_v)} \qquad (14)$$

or

$$p = \frac{1}{100} \cdot \frac{\pi D \cos \alpha_g \cos \alpha_v.P}{100\, m_g m_v (s_g + s_v)L} \cdot \frac{s_g + s_v}{s_g\beta_v + s_v\beta_g - \beta_g\beta_v} = \eta.p_k \qquad (14a)$$

where

$$\eta = \frac{1}{100} \cdot \frac{s_g + s_v}{s_g\beta_v + s_v\beta_g - \beta_g\beta_v} \qquad (15)$$

The actual beating pressure (p) can thus always be calculated from the edge pressure p_k provided that

the width of the fringes of stuff on the bars can be determined.

The various conditions which are liable to arise will now be examined.

If the widths of the fringes β_g and β_v are equal to or greater than s_g and s_v respectively, this will necessitate the parallelogram of contact being completely covered with stuff. In equation (15) β_g may then be set equal to s_g and β_v equal to s_v. Then

$$\eta = \frac{1}{100} \cdot \frac{s_g + s_v}{s_g s_v} \quad - \quad - \quad - \quad (15a)$$

Reference to equation (9) shows that in this case $p = p_f$.

If, on the other hand, the widths of the fringes are less than the widths of the bars, and if, as is usually the case, the angles α_g and α_v are small, then one may put

$$\beta_g = \beta_v = \beta \text{ and } \eta = \frac{1}{100} \cdot \frac{s_g + s_v}{\beta(s_g + s_v - \beta)} \quad - \quad - \quad (15b)$$

Finally, if the fringes are very narrow in comparison with the widths of the bars we get

$$\eta = \frac{1}{100} \cdot \frac{1}{\beta} \quad - \quad - \quad - \quad - \quad (15c)$$

Let us assume that it is required to compare the actual beating pressure exerted on the stuff in a number of different beaters, the stuff in all the beaters having reached the same beating stage. It will then be seen from the foregoing that one is able to assume with reasonable accuracy in the case of fairly stout beater bars, that the beating pressure (p) actually exercised on the stuff is proportional to the edge pressure (p_k); because with stout bars the value of $\beta_g \beta_v$ has little influence on the value of η. On the other hand, if

the bars are very thin, or the fibres very long, so that the value of $\beta_g\beta_v$ assumes greater importance, the conditions will not be as simple; and it will then be necessary to try and estimate the values of β_g and β_v in order to arrive at some estimate of the value of (p).

Let the average length of fibre be taken as $\frac{B_g}{\cos \alpha_g}$ or $\frac{B_v}{\cos \alpha_v}$. By occasionally measuring the length of the fibre during the beating process, it is possible to examine *how the beating pressure on the stuff increases as the fibres are shortened.* If the fibres were originally long enough to cover the whole of the surface f, then the value of η would require to be found from equation (15*a*). Later on in the beating process equation (15*b*) might be employed; and finally about the end of the beating process the value of η would probably best be found from equation (15*c*).

Example I.—

$$s_g = 2 \text{ mm.}; \; s_v = 8 \text{ mm.}; \; \alpha_g = 45°; \; \alpha_v = 0°.$$

The mean length of fibre λ is originally 3 mm. and after beating is 1 mm. Since $\frac{\lambda}{100} \cdot \cos \alpha_g = \beta_g > s_g$ we therefore find from equation (15*a*):—

$$p = \frac{1}{100} \cdot \frac{0{\cdot}002 + 0{\cdot}008}{0{\cdot}002 \times 0{\cdot}008} \cdot p_k = 6{\cdot}25\, p_k.$$

If the stuff has been shortened to the point where the mean length of fibre λ is 2 mm., then $\beta_g = 0{\cdot}002 \times 0{\cdot}71 = 0{\cdot}0014$ and $\beta_v = 0{\cdot}002$. From equation (15*b*) we get

$$= \frac{1}{100} \cdot \frac{0{\cdot}002 + 0{\cdot}008}{0{\cdot}002 \times 0{\cdot}002 + 0{\cdot}008 \times 0{\cdot}0014 - 0{\cdot}002 \times 0{\cdot}0014} \cdot p_k$$
$$= 8{\cdot}0\, p_k.$$

For $\lambda = 1$ mm. we get $\beta_g = 0{\cdot}001 \times 0{\cdot}71 = 0{\cdot}0007$ and $\beta_v = 0{\cdot}001$. From equation (15*b*) we then get

$$p = \frac{1}{100} \cdot \frac{0{\cdot}002 + 0{\cdot}008}{0{\cdot}002 \times 0{\cdot}001 + 0{\cdot}008 \times 0{\cdot}0007 - 0{\cdot}001 \times 0{\cdot}0007} \cdot p_k$$
$$= 14{\cdot}3\, p_k.$$

Example 2.—

$$s_g = s_v = 8 \text{ mm. } \cos \alpha_g \infty 1, \ \cos \alpha_v = 1{\cdot}0.$$

For the same lengths of fibre as in the above example we find from equation (15*c*) :—

for $\lambda = 3$ mm.; $\beta = 0{\cdot}003$; $\eta = \frac{1{\cdot}23}{0{\cdot}3} = 4{\cdot}1$; $p = 4{\cdot}1\, p_k$

for $\lambda = 2$ mm.; $\beta = 0{\cdot}002$; $\eta = \frac{1{\cdot}14}{0{\cdot}2} = 5{\cdot}7$; $p = 5{\cdot}7\, p_k$

for $\lambda = 1$ mm.; $\beta = 0{\cdot}001$; $\eta = \frac{1{\cdot}07}{0{\cdot}1} = 10{\cdot}7$; $p = 10{\cdot}7\, p_k$.

It is thus seen that the beating pressure (p) is approximately inversely proportional to the mean length of fibre, provided the latter does not exceed 2 to 3 mm.

CHAPTER V

THE INFLUENCE OF PRESSURE AND CONSISTENCY ON THE BEATING ACTION

IT has already been mentioned that the values of the coefficients c and c' (or k and k') depend on the consistency and on the beating pressure (p) which is exercised on the particles of stuff during beating. In the last chapter, this pressure in turn has been seen to vary with the average length of the fibres. The beating pressure (p) as such cannot, therefore, be taken into account for purposes of practical calculations, and it is necessary to deal only with the edge pressure (p_k), the value of p usually standing in some simple relation to the value of p_k. In comparing beating processes carried out at different pressures, the comparison is made on the basis of the edge pressures, which, for the same beating process, will bear approximately the same ratio to the beating pressure in the case of each of the beaters under comparison. In individual cases where the value of p_k will not serve as a basis of comparison, it is necessary in one way or another to estimate the true value of p. One such case has been referred to in the previous chapter.

Experimental data are much to be desired as to the effect of beating pressure and consistency on the beating effect (*i.e.*, on the values of c and c' or k and k'). A few tests have been carried out in this direction, but

they do not clear the matter up completely. In some of the experiments carried out by the author it was not possible to express numerically the degree of wetness of the stuff or the shortening effect on the fibres, because suitable apparatus was not available at the time. The experimental results described below will probably prove to be of some value, however, inasmuch as they tend to shed a little light on the action of the beater.

In addition to the work carried out by the author, use will also be made of the numerous beating tests carried out by Dr Schubert [1] at Darmstadt. Unfortunately, all these tests were carried out at consistencies of between 1 per cent. and 4 per cent., which are rather outside the field of practical mill conditions. The highest pressure employed was $p_f = 7{\cdot}15$ kg. per square centimetre, which corresponds to an edge pressure of 1·1 kg. per square centimetre. It would also be desirable to learn whether the tests were continued with still higher pressures, for in practice, as is well known, considerably higher pressures are frequently met with. Nevertheless these tests are of material scientific interest; and use will be made of some of Dr Schubert's curves in the present work.

Comparative trials carried out with a given beating process in different beaters would furnish a basis for judging the respective merits of the beaters, for discovering faults and for introducing improvements. It is, therefore, highly desirable that as much of this kind of data as possible should be collected and co-ordinated.

In view of the fact that the coefficients k and k' are functions of two variables—viz., consistency and pressure—they should, strictly speaking, be represented

[1] Schubert, Dissertation, Darmstadt, 1919, "Ueber den spezif. Mahlungsgrad und dem spezif. Mahlungskoeffizienten bei der Hollaenderarbeit."

by surfaces in a co-ordinate system of three dimensions. For present purposes, however, it will be sufficient to represent them by means of plane curves ; and each coefficient will be shown as a function of the pressure at various consistencies, or as a function of the consistency at various pressures.

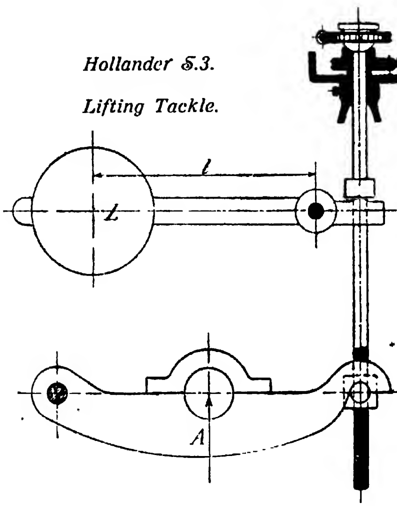


FIG. 11.

(a) Experiments on the relation between the specific shortening performance (k) and the edge pressure (p_k).

With the object of investigating the effect of the pressure on the cutting action, a large number of tests were carried out on a beater known as S3. This was a double roll Hoffsuemer beater from which one roll had been removed and replaced by an agitator

or propeller intended to lift the stuff over the backfall. The beater was furnished throughout with bleached sulphite of one and the same cook. Beating was continued until a certain definite shortening of the fibres had been effected regardless of the degree of wetness attained ; the precise moment of reaching this point being decided jointly by the engineer conducting the tests and the beaterman. The beating time re-

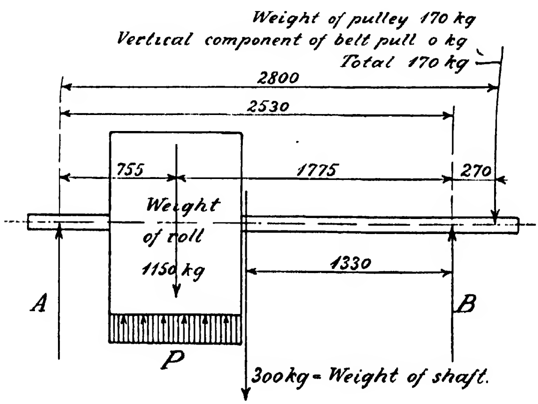


FIG. 12.

quired (T_m) was noted. The roll pressure was also noted and was kept constant during the tests. The weights and location of the centres of gravity of roll, shaft and pulley being known, the roll pressure could easily be calculated. The pull of the belt was horizontal, and, therefore, had no effect on the pressure of the roll on the bedplate.

The arrangement is indicated in Fig. 11. Bearing A rests on a lighter-bar, a lever device with adjustable counterweight enabling the weight of the roll to be

relieved at will. The bearing pressure A can be varied from zero to the point where the roll is practically freely suspended. The bearing pressure thus being known, it is simple to calculate the roll pressure P from the conditions of equilibrium, provided that the roll pressure is distributed uniformly over the surface of the bedplate. Great care was taken in the tests that this distribution should be even. Fig. 12 indicates the dimensions.

The value of p_k was calculated from the roll pressure P by means of the equation $p_k = \frac{P}{100K}$. The production of stuff per hour (q) was calculated from the beating time (T_m) and the furnish (Q); so that the value of k could be found from equation (10d).

The dimensions of the beating tackle were as follows:—

Diameter of beater roll, 1·1 m.
Length on face, 0·85 m.
96 flybars, each 4·5 mm. thick.
12 bedplate bars, each 4·5 mm. thick.

$$\cos \alpha_g \infty \cos \alpha_v = 1.$$

Number of revolutions per minute of roll, $n = 125$.
Peripheral speed of roll, 7·2 m. per sec.

$$L_s = 12 \times 96 \times \frac{125}{60} \times 0{\cdot}85 = 2040 \text{ m. per sec.}$$

$$K = \frac{12 \times 96 \times 0{\cdot}009 \times 0{\cdot}85}{\pi \times 1{\cdot}1} = 2{\cdot}55 \text{ m.}$$

The results of the tests are illustrated in Fig. 13.

It is obvious that the curve showing k as a function of p_k must pass through the axis of the co-ordinate system, for if p_k is equal to zero, then k will also be equal to zero. It is possible to plot the k-p_k curve with considerable accuracy. This is the curve for the

production of stuff per hour and metre cutting length per second for the given beating process.

(*b*) *Experiments on the relation between the specific shortening performance* (k) *and the consistency* (ρ).[1]

(1) These were also carried out in beater S3 described above and using an exactly similar furnish. The results are shown in Fig. 14A, the values of p_k and k being calculated in the same way as before. Beating was continued until a definite shortening effect had been

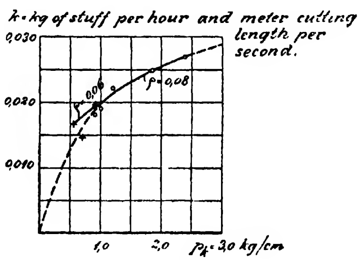


FIG. 13.

obtained regardless of the degree of wetness. A similar test was also carried out with rag half-stuff. It will be seen from Fig. 14A that with the edge pressure remaining constant, the cutting effect increases as the consistency decreases. This applies chiefly to beating processes carried out with low pressures or when hard rag half-stuff is being beaten. If the pressure is high the consistency will have no influence on the cutting action.

The increase in cutting effect with decrease in

[1] The consistency will henceforth be denoted by the symbol ρ, and expressed in kilograms of fibre per litre.

consistency can only progress up to a point, for it is clear that when the consistency is nil (*i.e.*, when there are no fibres present) there can be no cutting effect. It therefore follows that somewhere between nil and the consistencies employed in the tests there must be a critical consistency at which a maximum cutting effect will be obtained. Unfortunately the tests were not carried out at a sufficient number of different con-

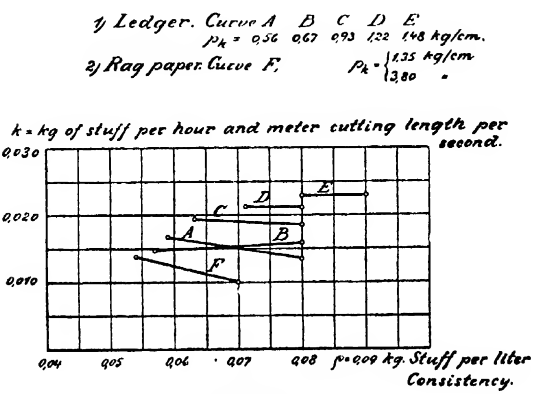


FIG. 14A.

sistencies to afford more information about this limiting condition.

Fig. 14A shows one apparently abnormal reading (the left-hand point of curve B). This test (B) was, however, altogether abnormal, as it also corresponds to the lower point indicated by a cross in Fig. 13. The point in Fig. 14A seems to be too low: one would expect to find it somewhere about the line for $\rho = 0{\cdot}06$. Thus the cutting effect in this test was too small, and it was also found that the power consumption was too low in proportion. The explanation is to be sought in the

fact that the spaces between the bedplate bars were clogged up with stuff, thus causing the cutting effect *as well as the power consumption to be reduced.*

(2) An experiment may here be referred to which has already been described in a former publication.[1] According to this one would expect to find a much more sloping curve than is shown in the previous example for the reduction in cutting effect. Professor Kirchner gave the following particulars of consistency, furnish, and time required for beating until the required degree of shortness had been reached :—

Consistency.	Furnish Q, Kilos.	Beating Time, T_m.	$q = \frac{Q}{T_m}$.
Per cent.	kg.	hrs.	kg.
7	450	2	225
7·6	500	3	167
8·0	520	over 3½	under 150

It will be seen from Fig. 14B that increasing the consistency from 7 to 8 per cent. has resulted in the production being reduced by about one-half. The author understood from Professor Kirchner, who carried out the tests, that the roll pressure was the same in all three cases.

The greater slope of the curve in Kirchner's tests would appear to conflict with the results obtained by the author as depicted in Fig. 14A. The explanation of the apparent discrepancy is that the decrease in production (cutting effect) is not a direct consequence of the increase in consistency; but is due to the fact that at the higher consistencies the cells do not gather up and retain as much stuff, and the quantity of stuff

[1] *W.f.P.*, 1917, p. 2119; and 1918, p. 519.

deposited on the bar edges (fibrages) is, therefore, smaller than with a thin furnish. Kirchner gives the rate of travel of the stuff in litres per second, and from

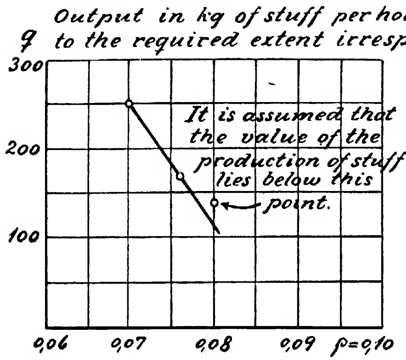


FIG. 14B.

this the amount of stuff in the cells can be calculated as follows :—

If V is the quantity of stuff passing a given point in the trough in litres per second, and x is the depth

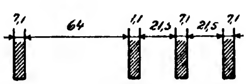


FIG. 14C.

to which the cells are filled (assuming for purposes of calculation that they are filled to a uniform depth, and that the stuff is evenly distributed in each cell as shown in Fig. 15), then

$$x = \frac{V.d_r}{(d_r - s_2).v.L} \qquad (10)$$

The following are the values for these depths (x) calculated from Kirchner's data on the basis of equation (16) :—

TABLE I

Consistency.	Circulation in Litres/Second.	Height of Stuff in Front of Roll.	Depth of Stuff in Flybar Spaces.
Per cent.		mm.	mm.
7·0	147	350	12·5
7·6	32	150 to 180	2·7
8·0	15	a few centimetres.	1·25

It is seen from the above table that at the higher consistencies the stuff travelled very slowly and that the roll was only submerged in the stuff to a depth of

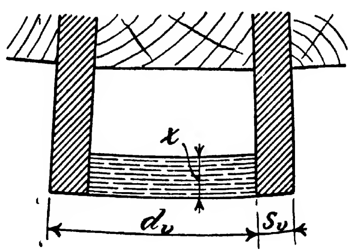


FIG. 15.

a few centimetres, so that the cells could not have filled properly. Under such conditions it follows that only an extremely small quantity of stuff could be deposited on the edges of the flybars and bedplate bars; for in order to form substantial fibrages an energetic eddy action in the cells is essential. Moreover, the bars were

spaced too closely together, the spacing being 64-21·5-21·5-64 mm. as shown in Fig. 14C.

It is obvious that with an interval of only 21·5 mm. between bars and such a slow rate of travel as occurred in Kirchner's tests, the eddy action, and consequently the formation of fibrages, would be materially diminished. This accounts for the steep slope of the production curve. The stuff in the 8 per cent. consistency test actually turned grey in beating, indicating that the small fibrages were so much abraded between the surfaces of the bars that the latter came into direct contact with one another.

(c) Experiments to determine the relationship between the specific "wetting" performance k' and the edge pressure p_k.

As has already been explained, the wetness of the stuff is produced partly by the treatment of the fibres between the surfaces of the bars and partly owing to the "whipping" of the stuff by the flybars. The individual effect of each of these factors can be determined by first measuring the degree of wetness produced by the whipping action and then subtracting this figure from the total degree of wetness produced by whipping and beating jointly. The difference gives the effect due to the actual beating (treatment between the bars) alone. Before considering the effect of consistency and roll pressure on the coefficient c' it is, therefore, first necessary to determine the effect of whipping.

In all the work carried out subsequently, the Schopper-Riegler beating tester was employed for measuring the degree of wetness (beating degree) of stuff. At the time the tests just about to be described were carried out, however, this apparatus had not yet become available, and it was necessary to employ a

home-made apparatus of slightly different dimensions, the readings of which are, therefore, not properly comparable with those of the Schopper-Riegler.

In order to determine the influence of whipping on the degree of wetness of the stuff, the roll must from time to time be raised for a period of half an hour or an hour, the degree of wetness being ascertained at the commencement and conclusion of each such period.

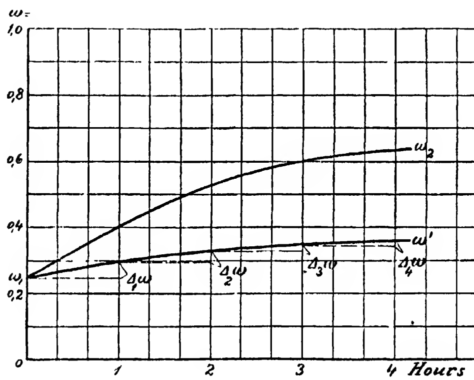


FIG. 16.

If, as is indicated in Fig. 16, the wetness increases in the following manner, viz. :—

During the first hour by $\Delta_1\omega$
,, second hour by $\Delta_2\omega$
,, third ,, $\Delta_3\omega$
and during the nth ,, $\Delta_n\omega$

then it may be assumed that the effect of whipping corresponds to a continuous beating process, and

$$\omega' - \omega_1 = \Delta_1\omega + \Delta_2\omega + \ldots + \Delta_n\omega.$$

In experiment No. 12 (see Fig. 17) the effect of whipping was determined. In the first hour $\Delta\omega$ was

0·07; later $\Delta\omega$ became equal to 0, there being no further increase in wetness. Therefore

$$\omega' - \omega_1 = 0{\cdot}07.$$

The following tests were carried out in a modern beater (number MIII3) beating Kraft pulp for spinning

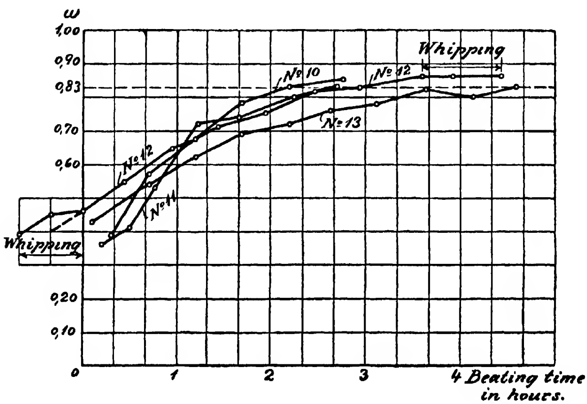


FIG. 17.

papers. The dimensions of the beating tackle were as follows :—

Diameter of roll, 1,350 mm.
Length on face of roll, 1,150 mm.
84 flybars, each 17 mm. thick.
19 bedplate bars, each 17 mm. thick.
Speed of roll, $n = 125\text{-}130$ revs. per min.
Peripheral speed, $v =$ approx. 9·2 m. per second.

Both the flybars and bedplate bars were set approximately parallel to the axis of the roll, so that

$$\cos \alpha_v = \cos \alpha_g \infty 1.$$

On examining the beating tackle after the tests were completed, it was found that of the nineteen bed-plate bars only fourteen had been actually functioning.

$L_s = 2930$ m. per sec. at 130 revs. per min.
$L_s(s_g + s_v) = 91$ sq. m. per sec.
$K = 9{\cdot}9$ m.

The degree of wetness of the original stuff (before beating) was 0·40. As soon as the value 0·83 had been reached, the beating was considered to have been completed (see Fig. 17). Since the whipping had produced an increase in wetness of 0·07, it follows that the treatment between the bars increased the wetness from 0·47 to 0·83.

Thus $\omega_2 - \omega' = 0{\cdot}83 - 0{\cdot}47 = 0{\cdot}36$. From equation (11*c*) we find :—

$$q' \times 0{\cdot}36 = c' L_s(s_v + s_g) = c' \times 91$$

$$c' = \frac{0{\cdot}36}{91} \times q' = 0{\cdot}004\, q'.$$

The furnish Q in these tests (Tests Nos. 10, 11, 12, and 13) was in each case 285 kilos. The beating time T_w can be seen from Fig. 17 : from this the value of q', and from the above equation the value of c', can be calculated.

The values for c' so determined could if desired be illustrated in a c'-p_k curve. This curve is, however, not shown, since the effect of whipping is comparatively small and tests are rarely carried out with sufficient thoroughness to determine accurately the individual effect of the whipping.

On the other hand, the k'-p_k curve has been drawn, and this facilitates comparison with other similar curves.

The values of c' and k' are given in Table II., and

the values of k' are shown graphically in the k'-p_k curve in Fig. 18 (curve A).

TABLE II

Test No.	Q.	T_m.	q'.	c'.	k'.	P.	p_k.	Shortening Effect.
								Mean Fibre Length.
10	285	$2\frac{1}{6}$	130	0·52	1·42	2400	2·42	1·23 mm.
11	285	$2\frac{2}{3}$	106	0·42	1·16	2400	2·42	1·65 ,,
12	285	about $3\frac{1}{2}$	82	0·33	0·90	1645	1·67	...
13	285	4	71	0·28	0·78	1645	1·67	about 1·70 mm.

Every half-hour samples were taken from the beater for microscopic examination by Clayton Beadle's method. The results are shown in Fig. 19.

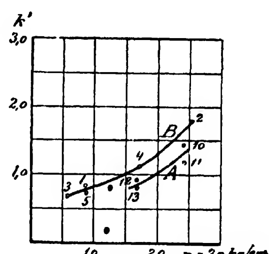


FIG. 18.

(1) From the lengths of fibre measured at the conclusion of beating for wetness, which are given in Table II., it is seen that the cutting effect in test No. 10 was greater than that in the subsequent tests. This was due to the fact that the roll and bedplate were ground immediately prior to this test (with sand), leaving a burr on the edges of the bars and increasing the cutting action. This burr gradually wore off as the beating progressed.

(2) Tests were also made on Beater MIII3 using

thinner bars. These tests were carried out in a similar manner to those just described. The dimensions of the beating tackle were as follows :—

Diameter and length on face of roll as before, viz., diameter 1,350 mm., length on face, 1,150 mm.
84 flybars, each 7 mm. thick.
26 bedplate bars, each 8 mm. thick.

$L_s = 5420$ m. per sec. at 130 revs. per min.
$L_s(s_k + s_m) = 81$ sq. m. per sec.
$K = 8{\cdot}9$ m.

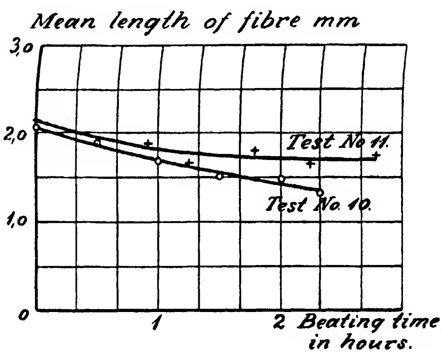


FIG. 19.

In these tests also the wetness was measured with the Schopper-Riegler beating tester, but at a different consistency from the previous tests, so that the respective degrees of wetness are not directly comparable with one another. It was, therefore, necessary to depend on the judgment of the beaterman; and the beating times shown in Table III. were assessed in this way.

From the furnish Q and the beating time T_w the

value of $q' = \frac{Q}{T_w}$ can be calculated; and equation (11*d*) then gives

$$k' = \frac{q'}{81}.$$

TABLE III

	Q.	T_w.	q'.	k'.	P.	p_k.	Shortening Effect.
1	285	about $4\frac{1}{2}$	66	0·81	760	0·85	Slightly too long.
2	285	2	143	1·76	2240	2·52	„ „ short.
3	275	$5\frac{1}{12}$	54	0·67	500	0·56	Very slightly too long.
4	285	$3\frac{1}{4}$	88	1·09	1520	1·71	Right length.
5	250	about $4\frac{1}{3}$	58	0·72	760	0·85	Very slightly too long.

Table III. shows the values of k' found experimentally for various values of p_k: they are also illustrated graphically in curve B of Fig. 18. It will be remarked that this curve, which must pass through the origin, commences as a straight line and then rises more steeply at the highest edge pressures.

As previously mentioned, Dr Schubert [1] in 1919 published data relating to a few series of tests carried out with a small experimental beater at the Technical College in Darmstadt. For the purpose of measuring the degree of wetness of the stuff, he designed a special apparatus which indicates the reluctance of the stuff to part with its water and thus furnishes a guide to its wetness. The raw materials under test were all beaten to the same definite degree of wetness. The beating time required to effect this is denoted by T_w (hours). This time is dependent on the pressure and consistency,

[1] Dr. Ing. Schubert, Dissertation, Darmstadt, 1919.

and the curves shown in Figs. 20A, B, C, D, and E have been drawn on the basis of Dr Schubert's curves. They illustrate the relation between the specific wetting performance and the pressure at consistencies of 1 per cent. and 4 per cent.

The principal dimensions of the small experimental beater were as follows :—

Diameter of roll, 0·3 m.
Length on face, 0·4 m.
Peripheral speed of roll, 7·67 m. per sec.
51 flybars, each 3 mm. thick.
16 bedplate bars, each 3 mm. thick.

$$\alpha_v = 7^\circ \; ; \; \alpha_u = 0^\circ.$$

From the dimensions it is found that

$$L_s(s_g + s_v) = 9 \text{ sq. m. per sec. and } K = 1{\cdot}18 \text{ m.}$$

Substituting 9 sq. m. for the expression $L_s(s_g + s_v)$ in equation (11*d*) we have

$$k' = \frac{q'}{9} = \frac{Q}{9T_w}.$$

At a consistency of 4 per cent. the furnish of the beater was 1 kg. of dry stuff : for thinner consistencies it was correspondingly less. The beating times (T_w) have been taken from Schubert's original curves.

The graphs in Figs. 20A, B, C, D, and E, corresponding to Schubert's Figs. 5, 8, 11, 14, and 17, represent the k'-p_k curves for linen, cotton, sulphite, mechanical wood and straw at consistencies of $\rho = 0{\cdot}01$ and $0{\cdot}04$ kg. of stuff per litre (1 per cent. and 4 per cent.).

(*d*) *Experiments to determine the relation between the specific wetting performance k' and the consistency* ρ.

Figs. 21A, B, C, D, and E, corresponding to Schubert's Figs. 4, 7, 10, 13, and 16, show the k'-ρ curves for linen,

cotton, sulphite, mechanical wood and straw, for edge pressures $p_k = 0{\cdot}1$ and $1{\cdot}0$ kg./cm. It will be noticed that these curves, just as the k-ρ curves, show a maximum

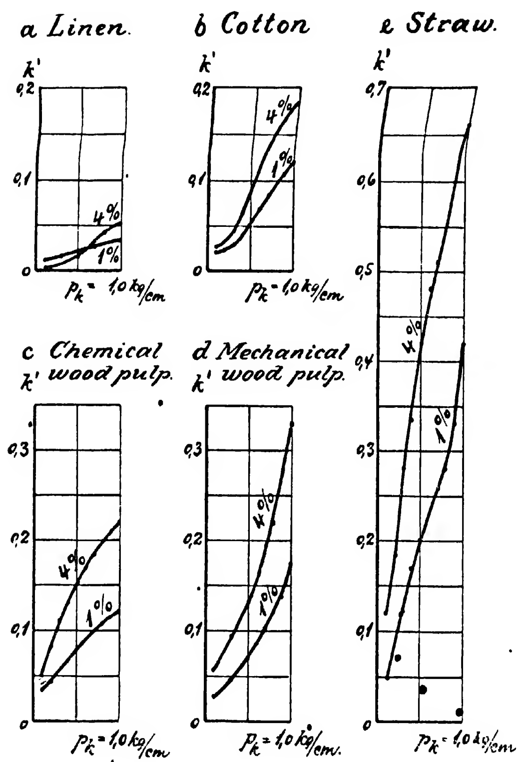


FIG. 20.

value for ρ, so that at consistencies above or below this critical point the wet beating effect is less than the maximum.

In other words, with a given raw material, beating tackle and roll speed, there is a certain critical con-

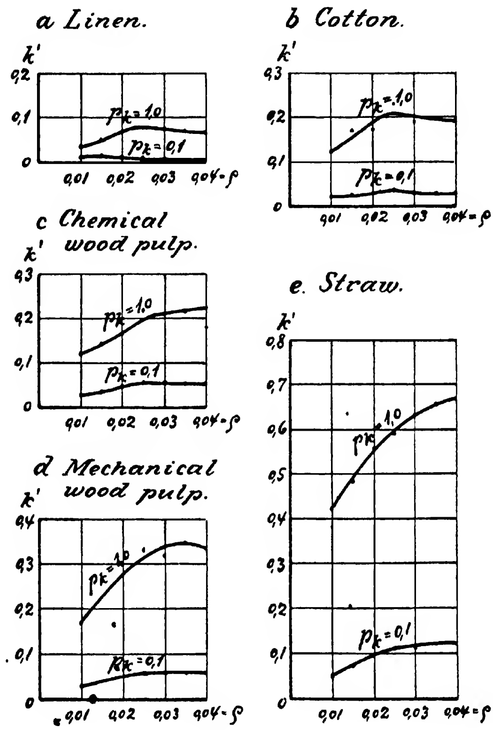


FIG. 21.

sistency at which the maximum shortening effect will be obtained, and similarly, a critical consistency at which the maximum wetting effect will be obtained.

CHAPTER VI

COMPARATIVE BEATING TESTS

WE shall now endeavour to apply the theory which has been developed to a few examples taken from practice. Unfortunately few records of tests are available in which all the conditions (particularly the roll pressures) have been observed with sufficient care and thoroughness to afford a reliable basis for a comparison between two beaters.

It is only possible to compare beating processes in which similar half-stuff is converted into similar whole stuff. Comparisons are impracticable between beating processes in which different raw materials or half-stuffs are employed; because the inherent characteristics of the materials, such as divisibility, softness, capacity for absorbing water, etc., are not taken account of in the formulæ, and also because the beating process is influenced by the initial condition of the stuff (length of fibre, whether kollerganged or not, etc.).

(1) Clayton Beadle and Stevens have carried out a beating test with sulphite in a large and a small beater.[1] (For experimental data, see p. 78.)

In both of these tests the beaten stuff turned out exactly the same. The roll pressure was not stated; and it must, therefore, be assumed to have been such

[1] The tests are described in Clayton Beadle and Stevens' "Theory and Practice of Beating," and in Kirchner's "Das Papier. IV., Ganzstoffe," p. 191.

as to produce the same edge pressure (p_k) in each beater, as this offers the most likelihood of producing two stuffs of similar character. Since the consistencies were approximately equal, it follows that with equal edge pressures, the values of the coefficients c and c' must have been the same for both beating processes. The productions (q) should, therefore, be in the same ratio to one another as the cutting lengths (L_s) of the two beaters; and the wet beating effects in the same ratio *as the magnitudes* $L_s(s_g + s_v)$.

	Small Beater.	Large Beater.
Roll diameter (D) - -	940 mm.	1,400 mm.
,, length on face (L) -	890 ,,	1,050 ,,
Weight of roll (tons) -	2	3½
Revolutions per min. (n) -	320	130
No. and thickness of bars :		
Roll - - - -	60 at 7 mm.	100 at 7 mm.
Bedplate - - -	15 ,, 5 ,,	25 ,, 6 ,,
Cos α_k = - - - - -	cos 27° = 0·891	cos 12° = 0·978
Dry contents of beater (Q)	180 kg.	380 kg.
Beating time (T_m) hours -	2½	2½
Consistency per cent. -	6 per cent.	6·5 per cent.
Production per hour (q) -	72 kg.	152 kg.
Cutting length (L_s) - -	3,300 m./sec.	6,340 m./sec.
$K = \frac{m_g m_v (s_g + s_v) L}{\pi D \cos \alpha_k} =$ -	3·58 m.	8·33 m.

The cutting lengths (L_s) are in the ratio of 100 to 192; while the productions per hour are in the ratio of 100 to 211. The experimental results thus differ by about 10 per cent. from those predicted by calculation on the basis of the foregoing theory.

According to the theory, the wet beating effect of each beater should be proportional to the value of

$L_s(s_g + s_v)$ for each beater, *i.e.*, the wet beating effects should be in the ratio of

3300 (0·007 + 0·005) to 6340 (0·007 + 0·006) or as 100 is to 208.

The experimental observations showed that the stuff attained the same character in each beater; that is to say, the wet beating effect $q(\omega_2 - \omega_1)$ in each beater was proportional to the production per hour. In other words, the two "wetting" (wet beating) effects were in the ratio of 100 to 211, which coincides almost exactly with the calculated ratio of 100 to 208.

(2) *Kirchner*[1] *describes four tests, of which two* produced dissimilar stuffs and will, therefore, not serve for purposes of comparison. The other two tests were carried out in one and the same beater with rags, with and without the employment of a Strobach stuff propeller.[2]

The tests without the propeller were carried out at a consistency of 5 per cent.; and those with the propeller at a consistency of 5·77 per cent. The use of the propeller caused the rate of travel of the stuff to increase to the extent that the cells were filled to a depth of 15 to 16 mm.; whereas without the propeller this depth was only 10 mm.[3] In the aggregate the propeller was found to increase the production of the beater by 37 per cent.[4]

This increase in production may be attributed to the fact that the propeller enables stuff of thicker consistency to circulate, the increased consistency causing larger fibrages to be deposited on the bar edges.

[1] *W.f.P.*, 1918, p. 102.

[2] Strobach's stuff propeller is described in Kirchner, "Das Papier. IV., Ganzstoffe," p. 61.

[3] These values are calculated from equation (16).

[4] Because the beating time was reduced from 330 to 240 minutes.

Against this argument it might be urged that according to Fig. 14A the cutting effect diminishes as the consistency increases. Such diminution can, however, be amply counteracted by slightly increasing the roll pressure, as is also clear from Fig. 14A. The success of the Strobach propeller may, therefore, be attributed in many cases to the higher consistencies which it enables the beater to handle.

A propeller can, however, also be successful in operation for purposes other than employing a higher consistency. If the head of stuff in front of the roll and the rate of travel of the stuff are too small to allow the cells to fill sufficiently, the propeller will improve matters by helping to increase the head of stuff in front of the roll and so cause the cells to fill better and larger fibrages to be deposited on the bar edges. An example of this action is given in Kirchner, " Das Papier. IV., Ganzstoffe," pp. 61-62. The consistency both with and without propeller was 5 per cent. With the propeller working, the cells were filled to a depth of about 11 mm.; without the propeller this depth was about 2 mm. It is obvious that the latter depth is quite inadequate to induce a proper eddy action in the cells; and that there can consequently be no deposit of fibre on the bar edges (*cf.* also Fig. 14B). Moreover, when the propeller was in use the beating time was reduced from 6½ hours to 4 hours 50 minutes.

(3) Cases also exist in which increased speed of circulation has caused larger fibrages to be deposited on the bar edges without the aid of a propeller. Kirchner has carried out some experiments [1] in this connection which are of sufficient interest to warrant the whole of the data being reproduced here.

Both the following tests were carried out with spin-

[1] *W.f.P.*, 1918, p. 1734. Tests Nos. 12, 13, 21, and 22.

ning paper furnishes for a sheet of 40-43 g. per square metre substance.

	Test No. 12.	Test No. 13.
Roll diameter (D) - -	1,400 mm.	1,200 mm.
„ length (L) - -	1,400 „	900 „
Roll bars and thickness -	96 at 7 mm.	75 at 8 mm.
Bedplate bars and thickness	41 „ 6 „	24 at 6 mm., 4 at 10 mm.
Surface pressure (p_f in kg./cm.²)	5·9	6·5
Revolutions per minute -	138	158
Dry furnish (Q) - -	300 kg.	235 kg.
Consistency - - -	7·1 per cent.	6·9 per cent.
Beating time - - -	4·9 hours	5·75 hours
Production per hour (q) -	61 kg.	41 kg.
Cutting length (L_s) - -	12,700 m./sec.	4,970 m./sec.
Production per hour per metre cutting length per second (k) (specific shortening performance)	0·0048 kg.	0·0082 kg.

According to the theory, one would not anticipate such a marked difference as is indicated by the figures in the last line of the above table, for the consistency was practically the same in each beater and the difference in edge pressures between the two beaters was also not sufficiently great to account for the very material difference in cutting effect.

$$p_k = \frac{100\, s_k s_v}{s_k + s_v} p_f = 1{\cdot}9 \text{ and } 2{\cdot}44 \text{ kg./cm. respectively in each case.}$$

The proper explanation of the large difference in production between these two beaters is to be found by

examining what quantity of stuff was contained in the cells in each case.

The contents of the two beaters were 4,200 and 3,400 litres respectively. During the entire beating period these quantities of stuff travelled round the respective troughs 188 and 369 times, corresponding to a circulation of 44·6 and 62·5 litres per second respectively, or to a cell filling of 3·7 mm. and 11·8 mm. depth respectively. The filling of 3·7 mm. depth was too small at that comparatively high consistency (7·1 per cent.) to cause the requisite size of fibrage to be deposited on the bar edges.

The two following tests, Nos. 21 and 22, were carried out with one and the same beating tackle. For the latter test, however, the trough had been rebuilt in such a way as to permit the use of higher consistencies and therefore of higher beating pressures. The final constructional alterations resulted in the originally slow rate of travel being increased sevenfold, and enabled an adequate fibrage to be deposited on the bar edges. Kirchner's data are as follows :—

	Test No. 21.	Test No. 22.
Furnish (dry) (Q) - -	170 kg.	186 kg.
Consistency - - -	5·7 per cent.	6·2 per cent.
Surface pressure (p_f) - -	4·1 kg./sq. cm.	5·9 kg./sq. cm.
Speed of circulation - -	1·8 m./min.	12·5 m./min.
Beating time - - -	160 min.	115 min.
Production per hour - -	64 kg.	97 kg.

The results thus show that the production was increased by 50 per cent. owing to the causes described above.

(4) On p. 1734, *Wochenblatt fuer Papierfabrikation*, 1918, Kirchner discusses two further tests (Nos. 14

and 15) carried out in two different beaters with bast fibres. The following data are given :—

	Test No. 14.	Test No. 15.
Diameter of roll - - -	1·25 m.	0·80 m.
Length on face of roll -	0·85 m.	0·80 m.
Flybars - - - -	72 at 7 mm.	66 at 8 mm.
Bedplate bars - - -	30 ,, 5 ,,	14 ,, 6 ,,
Surface pressure (p_f) - -	5·7 kg./sq. cm.	5·0 kg./sq. cm.
Furnish (Q) - - -	124 kg.	81 kg.
Revolutions per minute -	130	200
Consistency - - -	4·1 per cent.	3·1 per cent.
Beating time - - -	2 hours	2½ hours

The following values were calculated from the above data :—

Cutting length per second -	3,980 m./sec.	2,470 m./sec.
Production per hour (q) - -	62 kg.	32·4 kg.
Production per hour per metre of cutting length per second (k) (specific shortening performance)	0·0156 kg.	0·0131 kg.
Edge pressure (p_k) - - -	1·66 kg./cm.	1·71 kg./cm.

Approximately the same edge pressures, but different consistencies, were employed in each test. The value of the coefficient (k) (the specific shortening performance), as calculated from the results of these tests, is found to be 20 per cent. higher in the case of the stuff of 4·1 per cent. consistency than with that of 3·1 per cent. This is in apparent contradiction with what one would expect according to the curves in Fig. 14A ; but the contradiction is only apparent, as the latter curves must possess a maximum value for (k), and somewhere between this point of maximum value and the origin the value of (k) must decrease with decrease of con-

sistency, since the curve must necessarily pass through the origin. It is interesting to note that with these low consistencies depths of stuff in the cells as small as 2·4 mm. and 2·0 mm. were sufficient to ensure the deposit of adequate fibrages on the bar edges (see below). With thin consistencies, the friction produced by that portion of the stuff which is not directly carried round by the roll is so small that fibrages will adhere to the bar edges, notwithstanding the poor eddy effect in the cells.

	Test No. 14.	Test No. 15.
Contents of beater - -	3,000 litres	2,600 litres
Number of times stuff circulates round trough during entire beating time	369	369
Rate of circulation - -	15·4 litres/sec.	10·6 litres/sec.
Depth of stuff in cells - -	2·4 mm.	2·0 mm.

(5) It was attempted to carry out in beater MIII3 the same beating process with various bedplates. The following tackle was employed :—

(i.) That described in Chapter V., p. 73, Tests Nos. 1-5, with 7 mm. flybars and 8 mm. bedplate bars.

(ii.) That described in the same chapter, pp. 69-70, Tests Nos. 10-13 with 17/14 mm. bars.

In assessing the progress of the beating, regard was had exclusively to the wetness of the stuff. The specific "wetting" performance (k') depends only on the nature of the stuff, its initial and final condition the pressure, and on the consistency. The value of k' should, therefore, be the same irrespective of the design and construction of the bedplate. In Fig. 18 curves are

drawn showing k' as a function of p_k for both bedplates. According to the theory, these two curves should coincide with one another. This they fail to do and there is a discrepancy of some 25 per cent.

It will be seen from the foregoing that the theory which has been elaborated provides in the main an explanation for all the observations made during the various tests. Results obtained by calculation have agreed fairly approximately with those obtained by experiment. Moreover, it has been seen possible to detect errors of design in the beater, where the cause of these has been due to too small a deposit of fibre on the bar edges. The tests show further that with thick consistencies the formation of eddies or revolving rolls of stuff in the cells is a condition essential to the deposit of fibrages on the bar edges. With consistencies of 6 per cent. to 7 per cent., the cells must be filled with stuff to a depth of 12 mm. to 15 mm. in order for an adequate eddy action to be developed. With thinner consistencies smaller depths of stuff are sufficient: with quite thin consistencies, 2 mm. may even be considered deep enough. The internal friction in the stuff increases very rapidly as the consistency increases. Consequently, that portion of the stuff which is not directly carried round by the roll, and therefore remains comparatively stationary, strongly tends to wipe off the fibrages from the bar edges if its effect is not counteracted by the eddy action in the cells.

Again, if the consistency is thick, it is necessary for the stuff to be thrown with considerable force against the edges of the bedplate bars in order to be retained thereon as fibrages. This can only be effected in the case of thick sluggish stuff if the cells are fairly well filled. It must be remembered that a depth of

10 mm. of stuff in a cell corresponds to a pressure head over the bedplate of 100 to 150 mm. (the centrifugal force is generally ten to fifteen times greater than the force which would be exerted by the stuff in virtue of its mere weight alone).

It is true that some of the experimental results deviate from the calculated ones: in one case the difference is 25 per cent. where the conditions were favourable to the deposit of fibrages on the bar edges. While such variations naturally do not confirm the theory, they should not necessarily be allowed to shake faith in it. It must be borne in mind that there are many possible sources of error in carrying out beating tests. Thus it is frequently very difficult to assess the beating time accurately: differences occur in the characters of the half-stuffs used in comparative trials; bedplate bar spaces are liable to become clogged with stuff to a fluctuating degree; a roll may not be running evenly and truly on its bedplate; the sharpness of the bars vary, and there are numerous other variable factors. Nevertheless no other beater theory has yet been advanced which agrees so closely with practice.

It is to be regretted that so few results of beating tests have been published, and that many of these embody insufficient data, or have not been carried out with the requisite care to enable them to be investigated critically on the lines laid down above. The author hopes, however, that his treatment of the subject will have aroused interest for scientifically conducted experimental work on these lines; and that the publication of a considerable number of *k*- and *k'*-curves may be awaited at an early date. Investigations of this kind involve some expenditure of time and trouble; but the results will be an ample recompense. A deeper insight into the beating process will rapidly lead to improve-

ments and to a more rational utilisation of time and power. Unfortunately the figures and results of tests published hitherto have not assumed an importance commensurate with the amount of labour spent in obtaining them ; for the reason that up to the present there has been no basis on which to compare them. It is hoped that the present treatise may provide such a basis.

PART II

POWER CONSUMPTION

CHAPTER I

MEASUREMENT OF THE POWER CONSUMPTION

HITHERTO we have dealt with the mode of operation of the beater, its output, and the character imparted to the stuff, *without taking any account of the power consumption*. The question of power consumption, however, is of equally great importance in any thorough investigation of the beating problem. The beaters are frequently the largest power-consuming aggregates in the mill, so that a few per cent. of saving may be of considerable economic importance. Moreover, the beaters absorb a large number of horse power which are wasted in the sense that they do not contribute to the actual beating of the stuff. The power which is consumed in the actual beating of the stuff is often only 25 to 50 per cent. of that required to drive the beater. It is, therefore, important to investigate not only the power used for beating but also the losses which occur.

Let N_M be the number of horse power required for the actual beating of the roll against the bedplate. (Power consumption of beating tackle.)

,, N_R be the power required merely to rotate the roll in the stuff (circulation and friction).

And let N_{LP} be the balance of the power consumption which represents chiefly friction losses in the bearings.

The value of N_{LP} can be calculated from the bearing pressures, which vary with P, the roll pressure.

If N is the total number of horse power consumed by the beater, we then have

$$N = N_M + N_R + N_{LP} \quad - \quad - \quad - \quad (17)$$

Let N_{LO} be the power consumption when the beater is empty and the roll lifted clear. This is the no-load power consumption and represents bearing losses and a little air resistance.

If now the beater is filled and the roll rotates in the stuff without beating, the power consumption will be

$$N_C = N_R + N_{LO} \quad - \quad - \quad - \quad (18)$$

The values of N, N_C, and N_{LO} can be directly measured where direct electric drive is available. The value of N_{LP} can be calculated with fair accuracy, as will be shown later, and we then have from equations (17) and (18)

$$N_M = N - N_C + (N_{LO} - N_{LP}) \quad - \quad - \quad - \quad (19)$$

Several authors [1] have laid down for the value of P the following expression :—

$$N_M = \frac{\mu P v}{75} \quad - \quad - \quad - \quad - \quad - \quad (20)$$

where μ is termed the beating coefficient.

From equation (18) we have

$$N_R = N_C - N_{LO} \quad - \quad - \quad - \quad - \quad (18a)$$

This portion of the power consumption is absorbed in the following two ways: for the whipping of the flybars against the stuff (in the cells) and for overcoming the friction between the rotating bars and the stuff in the cells on the one hand and the stuff in the trough

[1] Kirchner, "Das Papier. IV.," p. 39; Pfarr, "Hollaender," p. 10.

MILL....................... **BEATER TEST SHEET** *Date*...................

Beater for Machine No. III.
Beater No. 3.
Maker's Name.
Capacity, 3,700 litres.
Roll Pressure, P=1,645 kg.

Diameter of Roll, D=1,350 mm.
Length of Roll, L=1,150 mm.
Fly Bars, 84 x 17 mm.
Bedplate Bars, 19 x 14 mm.

L_s=3,880 m./sec. for n=127 r.p.m.
K=13·4 m.
v=9 m./sec. when n=127 r.p.m.
$L(s_r+s_k)$=120 m.²/sec.

s_k=14 mm.
s_r=17 mm.
$\alpha_k=0°$, $\alpha_r=2\frac{1}{2}°$.
$\cos\alpha_k=1$, $\cos\alpha_r=\propto 1$.

Time.	Motor R.P.M.	Roll R.P.M.	Counter-balance Weight.	Roll Pressure, P.	Volts.	Amperes.	Kilowatts.			Total Horse Power (N).	N_c (in H.P.).	$N-N_c$.	Speed of Circulation of Stuff.		Temp. of Stuff.	Beating Degree.*	Time from Commencing to Beat.	Peripheral Speed of Roll.	p_c.	$N_M=N-N_c+N_{LO}-N_{LP}$			
																	Hrs. Mins.	M/Sec.					
2.30	424	123	...	1,645	220	152	33·4	...	...	40·7	...	17·4	...	...	...	·52	0 05	8·7	1·23	0·118	...	...	...
...	428	126	...	0	225	92	20·7	...	...	...	23·8	...	...	...	...	...	...	8·9	...	...	...	...	...
3.10	427	124	...	1,645	220	144	31·7	...	...	38·5	...	16·1	...	...	...	·64	0 45	8·75	1·23	0·108	...	...	...
...	430	126	...	0	224	89	19·9	...	...	...	22·7	...	...	...	...	...	...	8·9	...	...	...	...	...
4.20	428	124	...	1,645	221	147	32·5	...	...	39·5	...	17·8	...	...	...	·76	1 55	8·75	1·23	0·120	...	...	...
...	434	127	...	0	224	87	19·5	...	...	...	22·2	...	...	...	...	...	...	9·0	...	...	...	...	...
5.30	431	125	...	1,645	220	148	32·6	...	...	39·6	...	17·5	...	...	...	·82	3 05	8·8	1·23	0·117	...	...	...
...	438	128	...	0	227	87	19·8	...	...	...	22·6	...	...	...	...	...	...	9·0	...	...	...	...	...
6.10	430	126	...	1,645	221	149	33·0	...	...	40·2	...	18·2	...	...	...	·84	3 45	8·9	1·23	0·120	...	...	...
...	439	129	...	0	226	87	19·7	...	...	...	22·5	...	...	...	...	...	...	9·1	...	...	...	...	...
7.55	434	127	...	1,645	224	157	35·1	...	...	42·9	...	20·4	...	...	...	·89	5 30	9·0	1·23	0·132	...	...	...
...	442	129	...	0	227	88	20·0	...	...	...	22·9	...	...	...	...	...	...	9·1	...	...	...	...	...

N_{LO}=2·7 H.P

N_{LP}=1·75–1·8 H.P.
$N_{LO}-N_{LP}$=0·9 H.P.

Mean Values.

N=40·2 H.P.
N_M=18·8 H.P.

$N_R=N-(N_M+N_{LP})$
=19·6 H.P.

Filling, from 2 P.M. to 2.20 P.M.
Beating, from 2.25 P.M. to 8 P.M.=5·35 hours, 18·8 H.P.,......104·5 H.P. hours.
Whipping, from 2 P.M. to 8 P.M.=6 hours, 19·6 H.P.,......117·6 H.P. hours.
No-Load, from 2 P.M. to 8.5 P.M.=6·5 hours, 1·8 H.P.,...... 10·9 H.P. hours.

Total—40·2 H.P., 233·0 H.P. hours.

Time to Empty and Wash Out.................

Furnish, 19 Sulphate.
2 Broke.
285 kg. Dry Stuff.
Consistency, 7·7 per cent.
Sheet..............

* By Schopper-Riegler Beating Tester.

on the other hand. These two sources of loss of power can be allowed for separately as will be shown later.

The tests described below were carried out with two direct electric-driven beaters, allowing speed variations of 1 : 1·7.

The no-load losses, armature resistance, and field currents were very carefully measured. Millivolt and ammeters were installed and the efficiencies of the motors determined at all loads and all speeds, so that for any given kilowatt input the horse power output to the belt was always known. The belt pull was practically horizontal and the motor mounted on slide rails.

The no-load power consumption of the beater (N_{LO}) was measured before and after each test and the mean value taken into account in the calculations. N and N_C were frequently measured during the beating process. The value of N_{LP} had to be calculated, as it was not possible to measure it directly.

The subjoined specimen beater test sheet indicates how the values of N and N_C were determined during the tests. Each time N was determined from the voltmeter and ammeter readings, the roll was immediately raised and the value of N_C also measured. This naturally eased the load on the motor, causing it to speed up a little, and in determining the value of N_C allowance had to be made for the altered motor speed.

By way of example we shall now proceed to calculate the value of N_{LP} for experimental beater No. MIII3. The roll was fitted with steel flybars 17 mm. thick and weighed 3,115 kilos. The weight (T) of the shaft was 600 kilos, and the weight (U) of the pulley was 640 kilos. The pressure on the bedplate will as usual be denoted by P. R is the pull in the slack side of the belt and $(R+r)$ the pull in the tight side. r is therefore the

effective tension. Figs. 22 and 23 indicate the forces which are in equilibrium during the rotation of the roll,

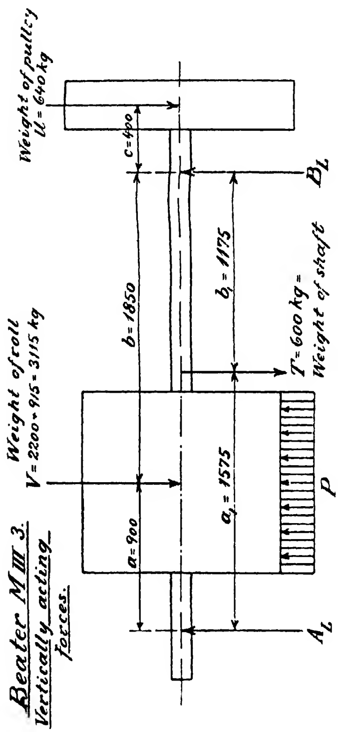


FIG. 22.

Fig. 22 showing the vertically acting forces, while Fig. 23 shows the horizontally acting forces.

The vertical bearing pressures A_L and B_L can be found from the following equations :—

$$A_L + B_R = V + T + U - P,$$
$$A_L(a+b) = Vb + Tb_1 - Uc - Pb,$$

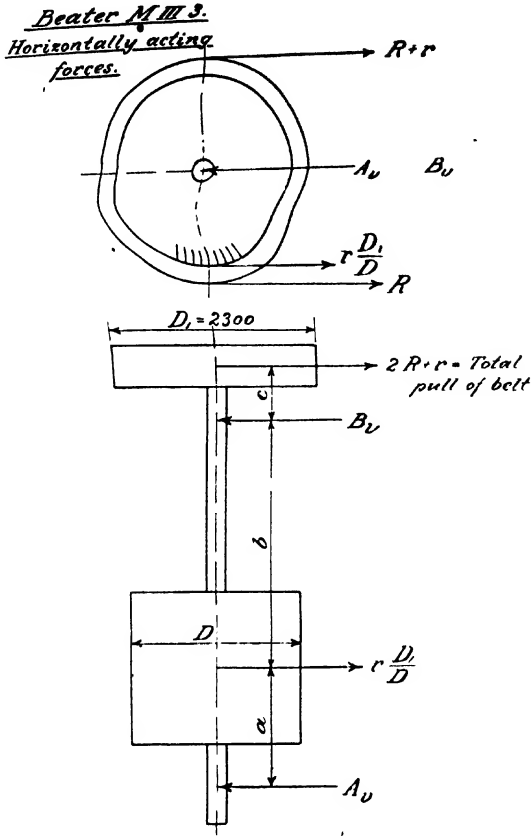


FIG. 23.

and substituting in these equations the values shown in Fig. 22 we have

$$A_L = 2263 - 0{\cdot}073\,P$$
$$B_L = 2092 - 0{\cdot}327\ P.$$

The values of A_L and B_L as well as those of (A_L^2) and (B_L^2) corresponding to various values of P are shown in Table IV.

TABLE IV

P	A_L.	B_L.	A_L^2.	B_L^2.
kg.				
0	2,263	2,092	5,120,000	4,360,000
925	1,640	1,790	2,700,000	3,310,000
1,645	1,156	1,554	1,340,000	2,420,000
2,400	648	1,304	420,000	1,710,000
3,155	138	1,062	19,000	1,130,000

Referring now to Fig. 23 and taking moments, the following equations are obtained for the horizontal bearing pressures, the friction in the bearings being neglected :—

$$A_V(a+b)+c(2R+r)=br\frac{D_1}{D}.$$

$$B_V(a+b)=(a+b+c)(2R+r)+ar\frac{D_1}{D},$$

where D_1 is the diameter of the pulley, and $D = 1{,}350$ mm.

The effective tension (r) in the belt is :—

$$r=\frac{75\times 60}{\pi}\cdot\frac{N}{D_1 n}=\frac{1430}{D_1}\cdot\frac{N}{n},$$

where N is the number of horse power transmitted by the belt.

The diameter of the pulley was 2·3 m. and the speed $n=125$ revs. per minute, so that

$$r=\frac{1430}{2\cdot 3}\cdot\frac{N}{125}\propto 5N.$$

Taking the tension in the slack side of the belt to be 200 kilos (R) and substituting in the above equations, we get :—

$$A_V=5N-58$$

and

$$B_V=8\cdot 5N+458.$$

The values of A_V and B_V so obtained, as well as those of (A_V^2) and (B_V^2) corresponding to various horse powers, are given in Table V.

TABLE V

N.	A_V.	B_V.	A_V^2.	B_V^2.
H.P.				
2·7	−45	481	2,000	232,000
10	− 8	543	64	296,000
15	17	585	289	342,000
20	42	628	1,760	395,000
30	92	713	8,400	510,000
40	142	798	20,000	640,000
50	192	883	37,000	785,000
60	242	968	58,600	940,000

Tables VI. and VII. give the values of the bearing pressures A and B calculated from their components A_L, A_V, and B_L, B_V for various roll pressures (P) and various horse powers transmitted by the belt.

TABLE VI

Bearing Pressure, $A = \sqrt{A_L^2 + A_V^2}$.

P.	N =							
	2·7	10	15	20	30	40	50	60 H.P.
kg.								
0	2,263	2,263	2,263	2,263	2,265	...	...	...
625	...	1,640	1,640	1,640	1,642	1,650	...	...
1,645	...	1,156	1,156	1,156	1,160	1,165	1,170	...
2,400	...	...	648	650	654	663	675	690
3,155	...	...	138	144	165	198	236	278

TABLE VII

Bearing Pressure, $B = \sqrt{B_L^2 + B_V^2}$.

P.	N =							
	2·7	10	15	20	30	40	50	60 H.P.
kg.								
0	2,140	2,155	2,165	2,180	2,200	...	...	...
625	...	1,870	1,885	1,900	1,930	1,960	...	...
1,645	...	1,650	1,660	1,680	1,710	1,750	1,790	...
2,400	...	...	1,430	1,450	1,490	1,530	1,575	1,625
3,155	...	...	1,210	1,235	1,280	1,330	1,380	1,440

The coefficient of friction, μ_L, for the journal friction is calculated from the following equation :—

$$\mu_L(A+B) \cdot \frac{\pi d_L n}{60 \times 75} = N_{LO},$$

where A and B are the bearing pressures corresponding to the power consumption at no-load. In the present case $n = 125$ revs. per minute. The diameter of the journal d_L is 130 mm. and $N_{LO} = 2{\cdot}7$ H.P. Therefore

$$\mu_L = \frac{230}{A+B} = 0{\cdot}053$$

(the value of $(A+B)$, according to the tables, being 4,403 kilos for $P=0$ and $N_{LO} = 2{\cdot}7$).

With a roll pressure P, horse power transmitted by the belt N, and at (n) revs. per minute we get

$$N_{LP} = 0{\cdot}053 \frac{(A+B)\pi d_L n}{60 \times 75},$$

or with $d_L = 130$ mm. and $n = 125$ revs. per minute,

$$N_{LP} = 0{\cdot}0006(A+B).$$

The values for N_{LP} (friction losses in the bearings) at 125 revs. per minute are shown in Table IX. as

calculated from this equation taken in conjunction with Table VIII.

TABLE VIII.—SUM OF THE BEARING PRESSURES (A + B) at 127 REVS. PER MINUTE

P.	N = 2·7	10	15	20	30	40	50	60 H.P.
kg.								
0	4,400	4,410	4,430	4,440	4,465	...	...	...
925	...	3,510	3,525	3,540	3,570	3,610	...	...
1,645	...	2,800	2,820	2,830	2,870	2,915	2,960	...
2,400	...	...	2,080	2,100	2,145	2,190	2,250	2,315
3,155	...	...	1,350	1,380	1,445	1,510	1,620	1,720

TABLE IX.—FRICTION LOSS, N_{LP}, IN THE BEARINGS CALCULATED FOR 125 REVS. PER MINUTE

P.	N = 2·7	10	15	20	30	40	50	60 H.P.
kg.								
0	2·70	2·70	2·72	2·72	2·74	...	...	...
925	...	2·11	2·12	2·12	2·14	2·16	...	...
1,645	...	1·68	1·69	1·70	1·72	1·75	1·78	...
2,400	...	...	1·25	1·26	1·29	1·31	1·35	1·39
3,155	...	...	0·81	0·83	0·87	0·92	0·97	1·03

The friction loss, N_{LP}, at other speeds with the roll raised can be found by assuming that the loss is directly proportional to the speed. Table X. gives the values calculated in this manner from the figures in the top row of Table IX. This method of calculation is not

strictly correct, as the belt tension will vary at different speeds ; but for all practical purposes the error involved may be safely neglected.

TABLE X

n.	N =		
	N_{10}	20	40 H.P.
85	1·81	1·84	1·87
94	2·00	2·03	2·07
103	2·16	2·19	2·26
115	2·44	2·48	2·52
129	2·70	2·80	2·80
134	2·85	2·90	2·95
143	3·04	3·08	3·15

CHAPTER II

THE POWER CONSUMPTION OF THE BEATING TACKLE. SPECIFIC POWER CONSUMPTION

In the previous chapter the work done in beating between the roll and the bedplate was shown to be expressed by $\mu P.v$. The coefficient μ is termed the beating coefficient, and we have seen how it is possible to measure the power consumption N_M of the beating tackle and so to determine the value of the beating coefficient.

In the literature on beating there are still evidences of uncertainty as to the nature of the beating coefficient. In the majority of cases it is regarded simply as a coefficient of friction. Some assume that the stuff is present between the roll and bedplate in a similar manner to the oil between a journal and bearing,[1] while others appear to believe that there is direct friction between the roll and the bedplate.[2] Again, there are those who regard the resistance to the rotation of the roll as being caused simply by friction between the surfaces of the bars and the stuff, looking upon both these as solid elements ; while yet others [3] consider that friction and shearing effects also occur in the interior of the thin layer of stuff between the bars, which effects

[1] Pfarr, " Hollaender und deren Kraftverbrauch," pp. 10-11.
[2] Clayton Beadle and Stevens, " Theory and Practice of Beating."
[3] Kirchner writes in this sense, " Das Papier. IV.," p. 41.

contribute towards the beating of the stuff. In addition to all these factors there is yet another source of resistance to the movement of the flybars, namely the cutting resistance which originates from the cutting action of the bars. When a shearing machine is in operation, a resistance to the shearing action of the blades is set up at the exact point at which the blades intersect one another. Referring back to Fig. 4 on p. 25 it will be seen that there are two different sources of resistance to the movement of the top shear blade, viz.: (1) the actual shearing resistance of the material being worked, and (2) a frictional resistance due to the lateral pressure which holds the two blades close up together and prevents the material from being "jammed" between the blades. If it be assumed that the material to be cut is the same length as the lower shear blade (L) then the work done in cutting can be expressed as (eL), where e is the amount of work (measured in metre-kilograms) which is required to effect a cut 1 m. long. Even if the lateral pressure should be insufficient to keep the blades tightly pressed together, so that jamming occurs and the material instead of being severed is abraded on both sides, then the expression eL will still represent the work done by the upper blade during its downward movement in passing the lower blade; for e represents the work required to move the blades past one another over a cutting length of 1 m. The frictional work due to the lateral pressure also has to be taken into consideration in addition to the work e.

Everything that has been said above of the shearing machine can be applied directly to the beater bars, having regard to the analogy which was developed in the earlier part of this book. The friction in question between the surfaces of the bars may under some conditions be simply ordinary friction between the bars

and the stuff; but it may also arise from a tearing of the layer of stuff between the bars (as Kirchner has envisaged): in either case the effect is to produce a resistance to the rotation of the roll. If f denote the coefficient of resistance, and P is the pressure of the roll, then fP will be the total resistance. In the first case f would be termed a coefficient of friction; whereas in the second case it would be more in the nature of a coefficient of tearing; but at the moment very little is known regarding it.

Employing the same symbols as before, the work done per second by the roll in passing over the bedplate may be expressed in the following way:—

$$75N_M = f.P.v + eL_s.$$

In the previous chapter this work was expressed by μPv, so that we now have

$$\mu Pv = f.P.v + eL_s \qquad - \quad - \quad - \quad (21)$$

or

$$\mu = f + e\frac{L_s}{P.v} \qquad - \quad - \quad - \quad - \quad (22)$$

If the beating coefficient μ is measured in the manner indicated in the last chapter it will soon be noticed that its magnitude depends on the working conditions which prevail in the beater, and it appears to be affected by so many factors that analysis seems at first sight to be hopeless. But a knowledge of these factors will tend to throw so much light on what occurs during beating between the bars, that they are well worthy of investigation. All records of the variation of power consumption during beating show that when beating rags the value of μ varies very considerably over the beating period and is much lower at the end than at the beginning.[1]

[1] See the power consumption curves of Arnold Rehn in "Kraftverbrauch beim Mahlen von Halb- und Ganzzeug." Also Strobach, *W.f.P.*, 1904, p. 2304, and Kirchner, *W.f.P.*, 1918, p. 910.

On the other hand, when beating chemical wood pulp, the value of the beating coefficient remains practically constant throughout the whole of the beating period. In a number of cases the author has investigated the behaviour of the beating coefficient and particularly the relation between the beating coefficient and the peripheral speed of the roll and the roll pressure (P). Below are given the results of investigations on the

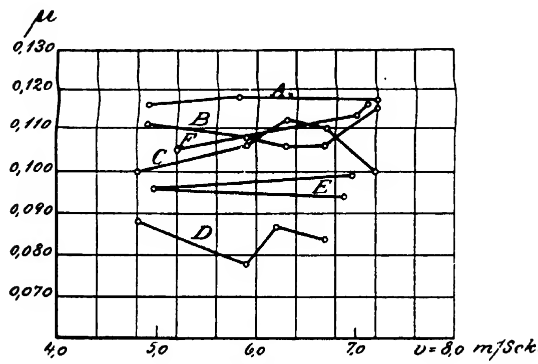


FIG. 24.

relation between the beating coefficient and the peripheral speed of the roll.

The curves in Fig. 24 show the values found for μ at various peripheral speeds (v). The data for curves A to E were obtained by beating sulphite in beater S3 at roll pressures of 302 to 448 kg. Although considerable errors occurred in taking the observations, the results of the tests clearly show that in the main the beating coefficient is independent of the peripheral speed. In the next chapter it will be shown that the value of the coefficient f is also independent of the

peripheral speed, and it is thus possible to prove that the power consumption for cutting (e) is also independent of the peripheral speed of the roll. This can be demonstrated quite simply as follows :—

Substituting $\frac{v}{\pi D}$ for $\frac{n}{60}$ in equation (1) we have

$$L_s = m_g . m_z . L . \frac{v}{\pi D}$$

and substituting this value for L_s in equation (22) we then get

$$\mu = f + e\frac{m_g . m_z . L}{\pi DP}.$$

It is thus clear that the power required for cutting (e) *must be independent of the peripheral speed* (v) of the roll, because μ and f are independent of v.

A large number of experiments has been made with the object of determining the relationship between the beating coefficient and the roll pressure, from which it appears that as the pressure increases so the value of the beating coefficient decreases. In the beaters employed for these experiments, chemical wood pulp was beaten mostly with $\mu = 0{\cdot}09$ to $0{\cdot}12$ and rag half-stuffs with somewhat higher values for μ ($0{\cdot}12$ to $0{\cdot}20$).

In the graphical representation of the results, the values of p_k are shown as abscissæ. In the course of the numerous investigations it has appeared that the diagrams are much easier to read if the values for μp_k instead of those for μ are taken as ordinates. This method of illustration affords a clearer survey over the effect of the individual factors on the power consumption.

The expression μp_k will be denoted by the symbol $\bar{\mu}$.

Now $p_k = \frac{P}{100K}$ and from equation (21) we therefore get

$$100\mu p_k K.v = 100 f p_k K.v + eL_s$$

and dividing both sides by 100Kv :—

$$\mu = \mu p_k = f p_k + \frac{eL_s}{100Kv} \quad - \quad - \quad - \quad (23)$$

Putting $Kv = L_s(s_g + s_v)$ (see p. 29) we then have

$$\mu = f p_k + \frac{e}{100(s_g + s_v)} \quad - \quad - \quad - \quad (23a)$$

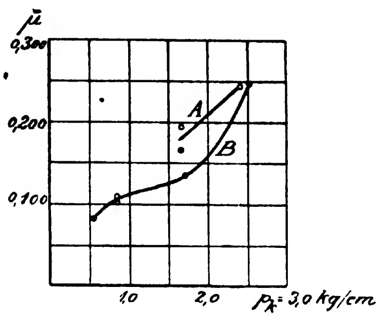


FIG. 25A.

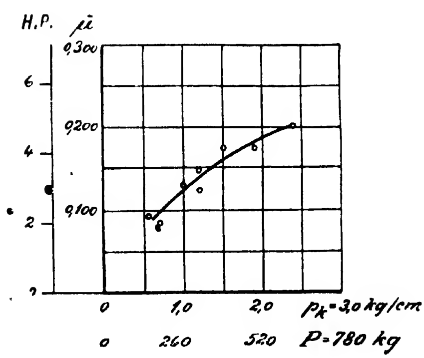


FIG. 25B.

From the equations $75\ N_M = \mu P v = 100 \mu K v$ it is seen that μ is the power consumption of the beating tackle per square decimetre of beating surface per second,

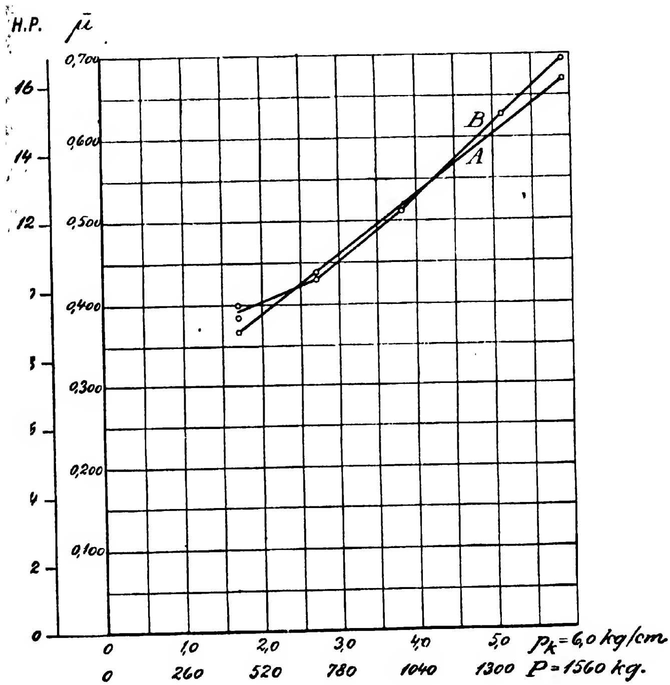


FIG. 25c

measured in metre-kilograms. μ is, therefore, termed the specific power consumption.

Figs. 25A and 25B show curves for $\bar{\mu}$ expressed as a function of p_k. These curves are based on the mean

value of $\bar{\mu}$ (averaged over the whole beating process and calculated on the basis of the momentary values of μ determined during the course of the beating process) at various roll pressures.

This method of procedure is applicable in the case of beating chemical wood pulp because the specific power consumption only changes slightly during this beating process.

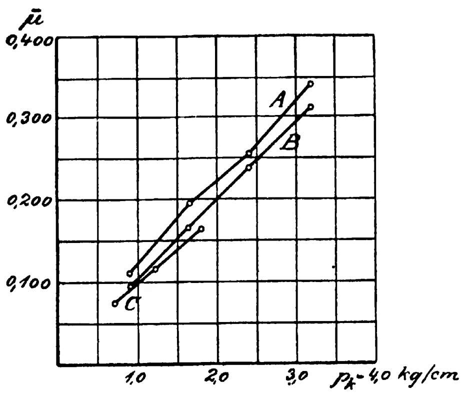


FIG. 25D.

It was not possible to carry out the beating process at a higher pressure than approximately 2·5 kg. per square centimetre, and for this reason the curves cannot be taken beyond this pressure.

A few $\bar{\mu}$-p_k curves were, therefore, obtained by varying the weight on the roll counterbalancing gear for short periods, and so obtaining readings of the power consumption at different loads. In this manner it was found possible to take readings at edge pressures up to 5 to 6 kg. per centimetre. If, however, it had been attempted to carry on beating for any appreciable

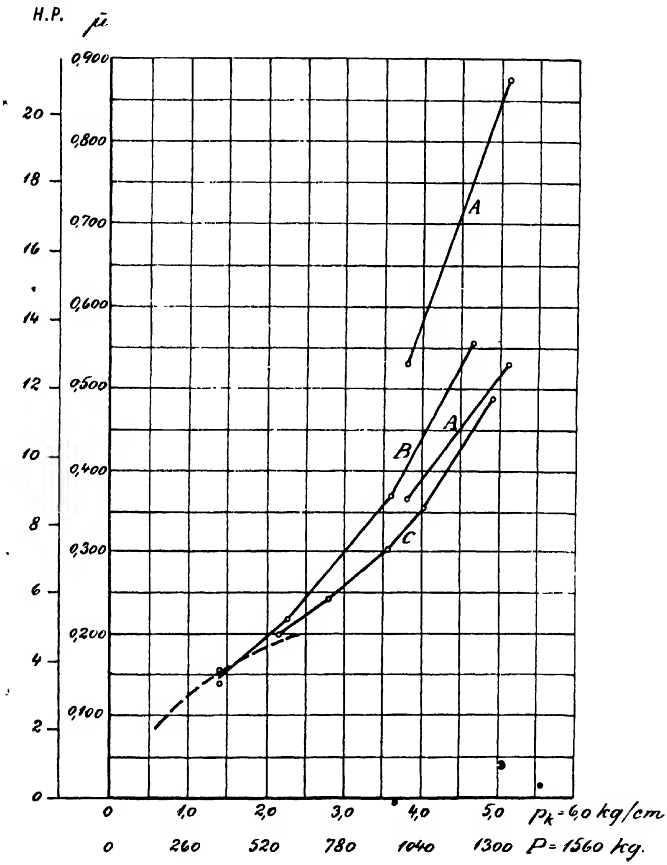

H.P.
μ
0,900
0,800
0,700
0,600
0,500
0,400
0,300
0,200
0,100
20
18
16
14
12
10
8
6
4
2
0
A
A
B
C
0
1,0
2,0
3,0
4,0
5,0
p_k = 6,0 kg/cm
0
260
520
780
1040
1300
P = 1560 kg.

FIG. 25E.

length of time at such high pressures, the stuff would have been rendered useless.

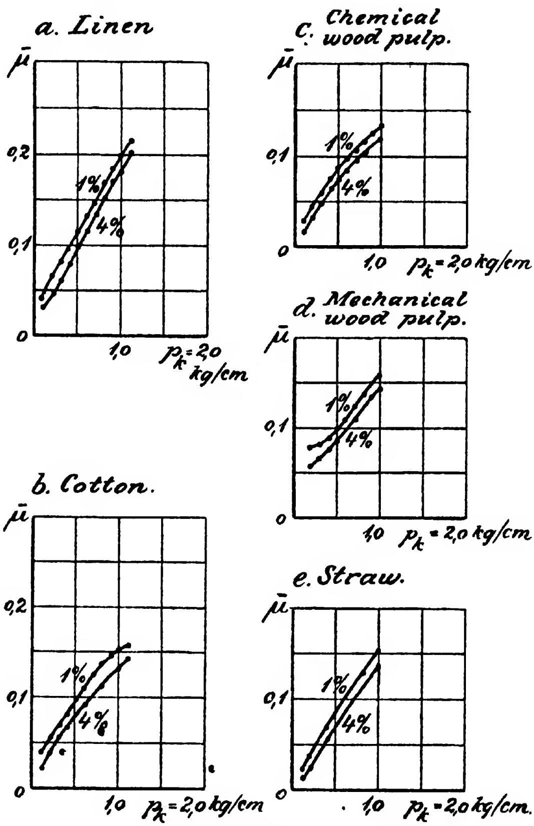


FIG. 26A-E.

All these curves indicate that different raw materials and different beaters give very varying values for $\bar{\mu}$.

While some curves are practically straight lines, others, such as in Fig. 25A, are S-shaped for the reason that the specific power consumption only increases slightly *within a certain zone. The variety in the shapes of the curves is probably closely related to the size of the fibrages on the bar edges: to the relation between the coefficients f and e, and the roll pressure: and to the condition and nature of the surface of the bedplate.*

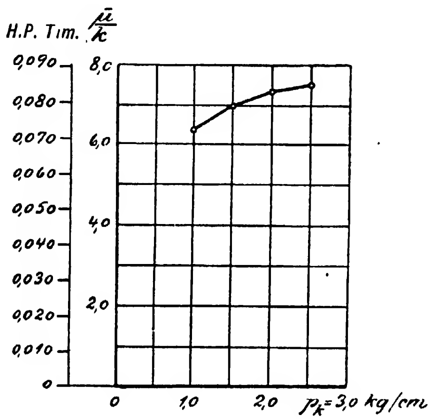


FIG. 27.

The coefficient f exercises most influence on the specific power consumption. It will be shown later how from the μ-p_k curves important conclusions may be deduced regarding the working conditions between roll and bedplate, when the factors are known which govern the magnitude of the coefficient f.

Schubert has carried out some similar experiments in connection with the power consumed for beating. The author has calculated the specific power consumptions corresponding to the results of these experi-

ments and they are illustrated in Fig. 26A-E in the same manner as those in Fig. 25.

It is of special interest to note that the experiments have shown that in order to beat chemical wood pulp (*in these* cases, sulphite and sulphate) a certain definite *number of horse-power hours* are required, irrespective of whether the beating is carried out under heavy or slight beating pressure. As has been pointed out, in beating these pulps, the power consumption (N_M) of the beating tackle only varies very slightly during the beating time. The total power consumption (horse-power hours) will, therefore, be :—

$$N_M T = \frac{100\bar{\mu} L_s(s_r + s_p).T}{75}$$

where $\bar{\mu}$ is the mean value of $\bar{\mu}$ during the process. Furthermore,

$$Q = k.L_s.T.$$

Dividing the former equation by the latter, we get the number of horse-power hours required to beat 1 kg. of stuff :—

$$\frac{N_M T}{Q} = \frac{100\bar{\mu} L_s(s_r + s_p)T}{75 k L_s T} = 1{\cdot}33(s_r + s_p)\frac{\bar{\mu}}{k}.$$

The values of $\frac{\bar{\mu}}{k}$ are depicted in Fig. 27, in which the values of $\bar{\mu}$ and k are taken from the curves in Figs. 25B and 13 which apply to the same experiments. It will be seen from Fig. 27 that the number of horse-power hours required to beat 1 kg. of chemical wood pulp remains approximately constant irrespective of whether the beating pressure is high or low.

CHAPTER III

EXPERIMENTS ON FRICTION AND TEARING

A LONG series of experiments was carried out with the object of investigating the conditions which determine the value of the coefficient f. Their original aim was to examine the relation between this coefficient and the pressure; but the experiments were soon extended so

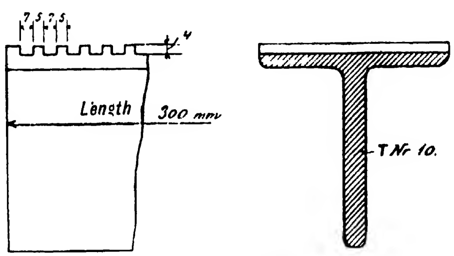


FIG. 28.

as also to cover the investigation of other factors. At the commencement the coefficient f was regarded merely as a coefficient of friction, and the first experiments were accordingly carried out as friction tests.

The investigations will be described in the sequence in which they were carried out, in order to enable the stages of development to be followed clearly.

8

The following materials were employed in the first experiments (friction tests) :—

(1) A steel bed with machined transverse grooves (Fig. 28).

(2) A smooth steel bed.

(3) A smooth phosphor-bronze bed.

All three beds were planed and showed coarse tool marks running along their length directions.

(4) A steel friction block with a sliding surface 19·2 sq. cm. in area (Fig. 29).

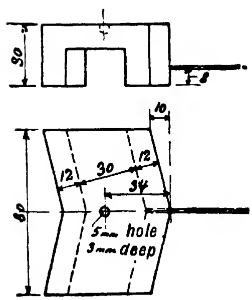


FIG. 29.

(5) A steel friction block (Fig. 30) with a sliding surface 9·6 sq. cm. in area.

Both friction blocks had their sliding surfaces

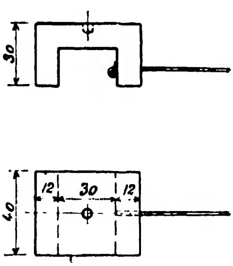


FIG. 30.

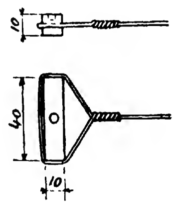


FIG. 31.

rough planed similarly to the beds with the tool marks running in the direction of motion of the blocks.

(6) A steel friction block (Fig. 31) with a sliding surface 4 sq. cm. in area.

(7) Two friction blocks (steel and bronze) (Fig. 32) with a sliding surface 2 sq. cm. in area.

(8) A steel friction block (Fig. 33) with a sliding surface 1 sq. cm. in area.

These friction blocks had their sliding surfaces filed smooth.

The bed was erected as shown in Fig. 34, and before commencing the tests, was adjusted so as to be exactly horizontal. A screw-threaded spindle was employed to draw the friction block over the bed, the spindle being connected to a spring balance which indicated the force required to move the block. Fig. 34 also

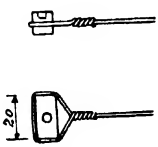


FIG. 32.

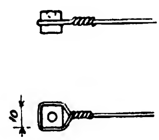
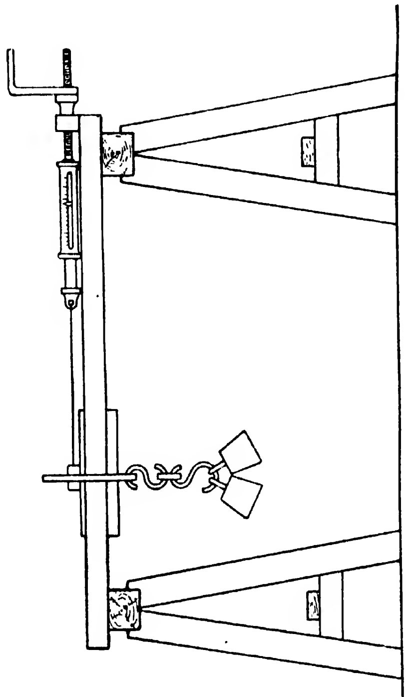


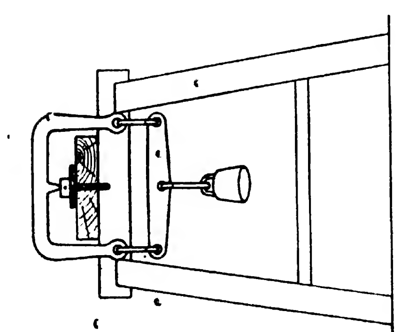
FIG. 33.

shows the yoke which with its attached weights enabled the friction blocks to be loaded to any desired extent.

First of all the coefficient of friction for steel on steel was determined, during which time water was poured over the bed. For the smooth bed the value for f was found to be 0·17, and for the grooved bed $f = 0·24$. Sulphite pulp of beater consistency was then poured on to bed No. 2.

A little water ran off and the stuff remained as a pulpy mass on which the friction block was placed and then weighted down. In this manner, using the friction blocks shown in Figs. 29 and 30, coefficients of friction between 0·65 and 0·82 were found corresponding to





loads of $p = 0{\cdot}75$-$1{\cdot}50$ kg. per square centimetre. Similar values were found for the grooved bed.

As stated in the previous chapter, the value of the beating coefficient μ was determined under the most varied conditions; but in no case was its maximum value found to exceed 0·22. It is obvious that the coefficient of friction f for the stuff rubbing against the working surfaces of the bars must be *less* than the beating coefficient μ (*cf.* equation (22)); and it therefore follows that the above described method for the determination of the coefficient of friction is unsuitable for the purposes here in view.

It appeared likely that the surfaces of the beds and blocks were so uneven as to offer in reality far more resistance to the motion of the stuff than would generally be offered by the working surfaces of beater bars. All the beds were, therefore, ground with emery and then filed accurately flat with the file marks running in the same direction as the planer tool marks had previously been. The intention was to produce a surface corresponding as closely as possible to the working surface of a beater bar. The latter is also not quite smooth, but usually has grooves worn into it in the direction of rotation of the roll.

After making these alterations the tests were resumed, the coefficient of friction for steel on steel and bronze on bronze being again determined as a preliminary step. In order to saponify any fats possibly present, the surfaces of the beds were washed with caustic soda and then flushed with cold water and a dilute solution of alum. The results of the friction tests then carried out are shown in Tables XI. and XII.

Table XI.—Friction Tests with Bronze on Bronze. Smooth Bed. Friction Block as shown in Fig. 32

Lubricant Consisted of Water Containing a Slight Quantity of Alum

Load on Friction Block.	Surface Pressure in kilos/sq. cm.	Coefficient of Friction after Washing Surface with Solution of Alum.
kg.		
8·2	4·1	0·18
13·2	6·6	0·19-0·23
18·2	9·1	0·25
23·2	11·6	0·26
28·2	14·1	0·28
33·2	16·6	0·27-0·33
38·2	19·1	0·31-0·36

Table XII.—Friction Tests with Steel on Steel. Smooth Bed. Friction Block as shown in Fig. 32

Lubricant Consisted of Water Containing a Slight Quantity of Alum

Load on Friction Block.	Surface Pressure in kilos/sq. cm.	Coefficient of Friction after Washing Surface with Solution of Alum.
kg.		
8·2	4·1	0·18
13·2	6·6	0·23
18·2	9·1	0·22-0·27
23·2	11·6	0·26
28·2	14·1	0·28-0·32
33·2	16·6	0·30
38·2	19·1	0·29-0·31

With a view to determining the value of the friction in the presence of sulphite pulp it was attempted to

repeat the plain friction experiments described above; but it did not prove at all easy to maintain steady conditions by these means, the tendency being for only that pulp to follow the block which was actually carried along by the block edge. Moreover, it was difficult to form any estimate of the thickness of the layer of stuff between the block and the bed; although this thickness affects the value of the coefficient of friction.

TABLE XIII.—COEFFICIENT OF FRICTION FOR SULPHITE PULP WITH VARIOUS SURFACE PRESSURES ON A GROUND AND FILED BRONZE SURFACE

Area of Friction Block in sq. cm.	Surface Pressure in kg./sq. cm.	Crêped Serviette Paper in:—			
		1 Layer.	2 Layers.	4 Layers.	16 Layers.
19·2 cm.^{2}	0·75	0·40-0·43	0·50	0·50-0·53	0·50
	1·25	0·38-0·42	0·50	0·52-0·54	0·52
	1·5	0·39	0·49	0·51-0·54	0·51
9·6 cm.^{2}	1·4	0·44	0·48	0·56	0·48
	2·5	0·38-0·45	0·49	0·53	0·51
	4·0	0·39-0·42	0·42-0·47	0·51	0·51
2 cm.^{2}	4·1	0·36	0·49	0·49	0·48
	5·4	0·42	0·42	...	...
	6·6	0·40-0·49	0·45	0·45	...
	7·9	0·39	0·45	...	...
	9·1		0·44	0·44	...
	11·6		0·43	0·43	0·47
	14·1		0·44	0·39-0·43	...
	16·6		0·44	0·36-0·42	...
	19·1		0·44	0·37-0·39	0·43-0·44

In order to obviate these uncertainties, the beater pulp was replaced by one or more layers of crêped serviette paper (crêped from unsized sulphite paper). The crêped paper was thoroughly softened in water containing a

TABLE XIV.—COEFFICIENT OF FRICTION FOR SULPHITE PULP WITH VARIOUS AREAS OF BLOCKS ON A GROUND AND FILED BRONZE SURFACE

Total Pressure on Stuff.	Area of Friction Block in sq. cm.					Number of Layers of Crêped Paper.
	1 cm.²	2 cm.²	4 cm.²	9·6 cm.²	19·2 cm.²	
kg.						
13·5	...	0·40-0·49	...	0·44	0·40-0·43	1 Layer crêped paper.
23·5	...	...	...	0·38-0·45	0·38-0·42	
38·5	...	...	...	0·39-0·42	0·39	
13·5	...	0·45	...	0·48	0·50	2 ,, ,,
23·5	...	0·43	...	0·49	0·50	
38·5	...	0·44	...	0·42-0·47	0·49	
13·5	0·44-0·39	0·47-0·45	0·53	0·56	0·50-0·53	4 Layers crêped paper.
23·5	0·45-0·39	0·48-0·43	0·53-0·54	0·53	0·52-0·54	
38·5	...	...	...	0·51	0·51-0·54	
13·5	0·49-0·41	0·49	0·53	0·48	0·50	12-16 ,, ,,
23·5	0·51-0·45	0·52	0·56	0·51	0·52	
38·5	...	...	...	0·51	0·51	

TABLE XV.—COEFFICIENT OF FRICTION AT VARIOUS SURFACE PRESSURES WITH A GROUND AND FILED STEEL SURFACE

Area of Friction Block in sq. cm.	Surface Pressure in kg./sq. cm.	Number of Layers of Creped Serviette Paper.					Remarks.
		1 Layer.	2 Layers.	4 Layers.	8 Layers.	16 Layers.	
19·2 cm.²	0·5	0·56 [1]	0·56	0·56	0·61	0·61	[1] The sheet tore after a movement of a few cm.
	1·0	0·65 [1]	0·60	0·67	0·66	0·66	
	1·5	0·57 [1]	0·65 [1]	0·66 [1]	0·65	0·69	
	2·0	0·58 [1]	0·65 [1]	0·64 [1]	0·65	0·65	
4 cm.²	2·0	0·49	0·55	0·55	0·61	0·61	
	4·5	0·49	0·55	0·60	0·63	0·63	
	7·0	0·53 [2]	0·57 [2]	0·58 [2]	0·63 [2]	0·64	[2] In these tests the block moved in short jumps instead of continuously.
	9·5	0·50 [2]	0·58 [2]	0·61 [2]	0·63 [2]	0·63	
1 cm.²	8·2	0·36 [1,2]	0·49 [1,2]	0·55 [1,2]	0·55 [1,2]	...	
	18·2	0·44 [1,2]	0·49 [1,2]	0·55 [1,2]	0·58 [1,2]	...	
	28·2	0·41 [1,2]	0·51 [1,2]	0·48 [1,2]	0·57 [1,2]	...	
	38·2	...	0·44 [1,2]	0·46 [1,2]	0·52 [1,2]	...	

small quantity of alum and then laid on the bed. The lubricant consisted of water with a slight addition of alum. In this way it was found to be comparatively easy to establish constant conditions. In the tests with the bronze bed and a movement of the block of 10 cm. the crêped paper only tore when a single layer was used, and the surface pressure reached or exceeded 6-7 kg. per square centimetre. With the steel bed the sheet tore at slightly lower pressures. The results of the tests are shown in Tables XIII., XIV., and XV.

It will at once be remarked that the grinding and filing of the surfaces did not have the anticipated effect; for the coefficients of friction are still considerably less than the values found for the beating coefficients. One must, therefore, conclude that the roughness of the surfaces is not a determining factor. Tests were carried out at various pressures (0·5 to 38 kg. per square centimetre) with friction blocks of contact areas varying from 1 to 19 sq. cm. and with 1 to 16 layers of crêped paper; but the values found for the coefficients of friction were all substantially higher than those of the beating coefficients. We find here the same lack of agreement as Haussner met with in carrying out similar experiments,[1] and which led him to doubt the accuracy of his experimentally determined beating coefficients.

Since there can be no doubt as to the correctness of either the beating coefficients or the coefficients of friction determined in the experiments described above, it is probable that the method adopted for measuring the coefficient of friction was not properly suited to the objects in view and that at speeds of 6 to 10 m. per second

[1] At the time of carrying out the above experiments, the author was unaware of Haussner's friction tests with woven materials between fluted blocks. *Cf. W.f.P.*, 1909, pp. 1960-65.

the friction effects are totally different from those obtaining at a speed of a few millimetres per second on which the above experiments are based. In fact, in some of the tests with the steel surface, the block moved forward in jerks, so that the statical friction was measured instead of the friction of motion. It may be mentioned, however, that as a general rule the tests in which the block showed a tendency to jerk were disregarded; as it was not possible under such conditions to determine the actual coefficient of friction.

TABLE XVI.—COEFFICIENT OF FRICTION OF SULPHITE PULP AGAINST A SMOOTH POLISHED BRASS PLATE. WATER AS LUBRICANT

Pressure.	Surface of Friction Block in sq. cm.		
	1	2	4
kg. 13·25	0·15	0·23	0·23
23·25	0·13	0·22	0·22

In the tests with polished beds it was remarkable to note that the coefficient of friction rose rapidly with the speed at which the block was drawn over the bed. At the instant of ceasing to turn the actuating screw the spring balance continued to draw the block a short distance at a diminishing speed; and the reading was only taken when the block had come to rest completely. The coefficients of friction corresponding to these conditions are shown in Table XVI. and apply to statical friction: they are lower than the values found with even the slightest movement. Occasionally, as

a matter of experiment, the block was moved rapidly and the coefficient of friction then rose as high as 0·8: the block (the sliding surface of which was not polished) then commenced to slide on the stuff, which consisted

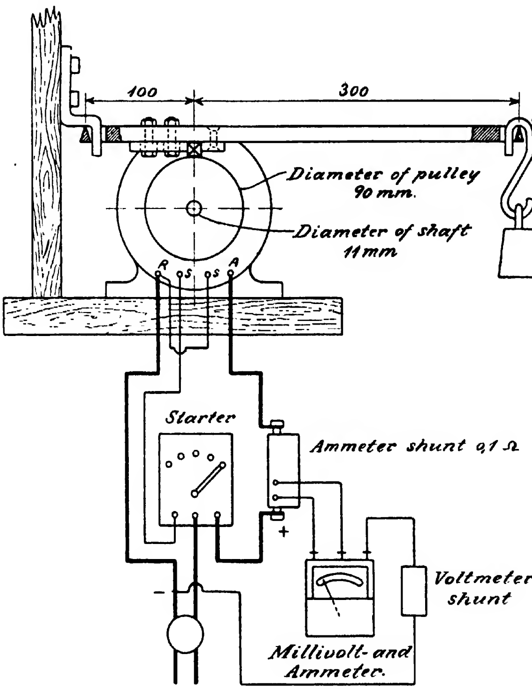


FIG. 35.

of four to eight layers of crêped paper. In these experiments it was also very difficult to obtain reliable results; trivial details being apt to exercise a very important effect on the values found for the coefficient of friction.

With a view to carrying out friction experiments under conditions approximating as closely as possible to those obtaining in the actual beater, the following arrangements were adopted: A cylindrical pulley 90 mm. in diameter was fitted to an electric motor of about $\frac{1}{3}$rd horse power at 2,400 revs. per minute. The cylindrical surface of the pulley was intended to take the place of the flat bed already described and was rough filed. After a few tests had been carried out, it appeared that this motor was too small and it was therefore replaced by a 1 horse-power motor with a speed of about 2,000 revs. per minute. The pulley was provided with a brake device, as shown in Fig. 35, consisting of a lever arm with a fitment for securing to it the friction blocks illustrated in Figs. 31, 32, and 33. A hook at the end of the lever arm carried the weights for varying the friction load on the pulley.

In the following equations the pressure exercised by the friction block will be denoted by p, and the velocity of the pulley by v. After the motor had been started up, the lever arm was placed in position and various layers of soaked unsized paper (made from the pulp under examination) were laid between the friction block and the pulley. During every test the power consumption was recorded from the readings of a combined millivoltmeter and ammeter. This instrument measured the armature current and the potential difference across the supply mains, *i.e.*, between the points marked + and −. The armature resistance r_a and the amount of current (i_o) taken at no load were first measured. The potential difference was 220 volts. In this way the bearing and air resistance losses together with the iron and other losses (T) were determined.

$$T = 220.i_o - i_o^2 r_a \text{ (measured in watts).}$$

The armature current i and the voltage e were then measured with the motor loaded. The horse power developed was, therefore,

$$\frac{i.e - i^2 r_a - T}{736}.$$

Considering now the brake, the horse power developed is given by

$$\frac{f.p.v}{75}.$$

So that we have

$$f = \frac{75}{736} \cdot \frac{ie - i^2 r_a - T}{pv}.$$

In this calculation no attention is paid to the fact that the pressure of the friction block on the pulley will increase the friction loss in the adjacent motor bearing. If the coefficient of friction in the motor bearing is taken at 0·03, it will be found by calculation that the effect of neglecting this additional loss is to make the value of the coefficient f appear higher than it should by 0·004.

It was possible to reduce the speed of the motor considerably, by means of the starting gear, thus also reducing the voltmeter reading. The observations obtained from the motor tests are recorded in Table XVII.

It will be seen from this table that at constant current the speed of the motor decreases in approximately the same ratio as the voltmeter reading. In other words, the work done by the motor at constant current consumption is approximately proportional to its speed. This fact was made use of in determining the value of the coefficient f at the lower velocities; it having been previously ascertained by test that the flow of current was practically constant for any position of the starting

handle. From this it follows that, certainly within the limits of 7-11 m. per second velocity, the coefficient f must be regarded as being independent of the velocity.

TABLE XVII

Starting Handle on Stop No.	For 1·00 Ampere.		
	Revs./min. (n).	Voltage (e).	$n : e$.
5	2,350	224	10·5
4	2,200	212	10·4
3	2,050	196	10·5
2	1,750	168	10·4
Starting Handle on Stop No.	**For 1·30 Amperes.**		
	Revs./min. (n).	Voltage (e).	$n : e$.
5	2,350	224	10·5
4	2,200	208	10·6
3	2,000	188	10·6
2	1,550	152	10·2

During the tests the stuff was retained in position under the friction block solely owing to the edge of the block holding the sheet fast. This was proved by trying to retain a small piece of sheet under the block without any of it projecting beyond the edges of the block: at every such attempt the sheet was instantly torn away by the pulley. Where several sheets of crêped paper were used together at low pressures, the friction was very great at the moment of starting the test, but rapidly diminished as the load caused the layers to be pressed together to a thickness at which the friction

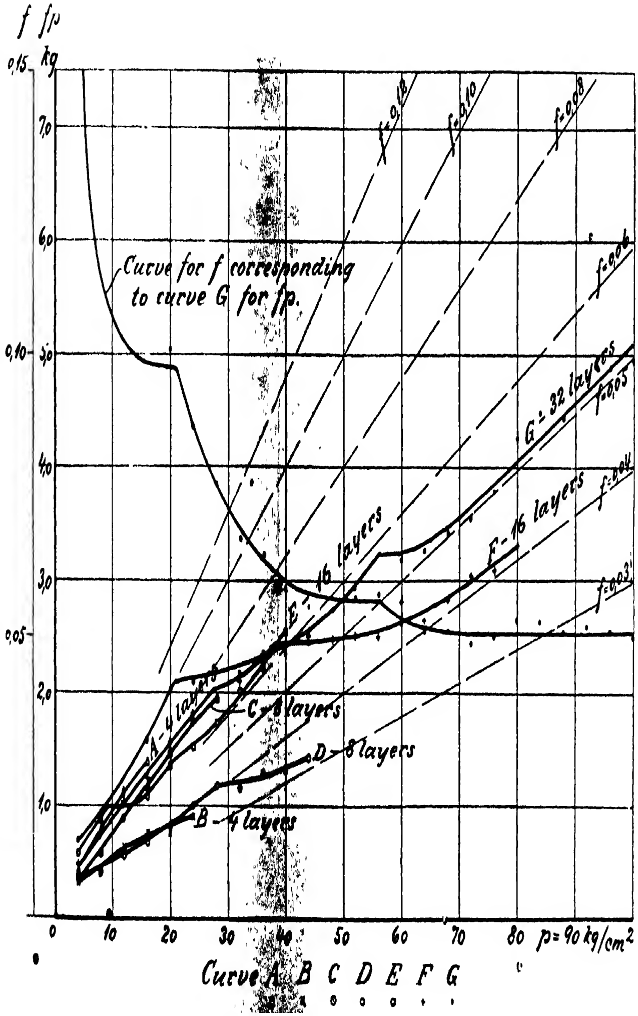
would remain constant for a fraction of a minute At this point the reading was taken. The pulley naturally wore down the paper very rapidly and as soon as it got thin the power consumption would suddenly begin to rise and frequently only a few seconds elapsed before metal was running on metal. When working with only a few layers of paper or at high pressures, no diminution in power consumption in the early stage of the test could be observed.

The following tests were all carried out with blocks of 1 sq. cm. area which had previously been ground with emery exactly to fit the cylindrical surface of the pulley.

The friction experiments were carried out partly with unsized uncrêped paper and partly with sample pieces of the bleached sulphite pulp from which the paper had been prepared. These latter samples were in lap form, 0·85 mm. thick.

The results are shown in Tables XVIII., XIX., and XX., and it will be seen that the governing factor is the condition of the stuff. In the experiments with the sulphite lap and the uncrêped paper, the test samples immediately became compressed into a compact mass of wooden or leathery consistency, not easily worn away and which gave a high value for the coefficient of friction throughout. Owing to the rapidly varying conditions great difficulty was experienced in taking observations

The crêped paper, on the other hand, behaved quite differently and gave one the impression of being in a condition corresponding to that of stuff in the beater. Just as in the beater tests the beating coefficient fell to very low values as the pressure increased; so also in testing these samples of crêped paper the coefficient f, fell to similarly low values. Even at very considerable pressures—up to 100 kg. per sq. cm.—the stuff did not



f fp
kg
0,15
7,0
6,0
0,10
5,0
4,0
3,0
0,05
2,0
1,0
0
10
20
30
40
50
60
70
80
p= 90 kg/cm²
Curve for f corresponding
to curve G for fp.
f=0,12
f=0,10
f=0,08
f=0,06
f=0,05
f=0,04
f=0,03
G - 32 layers
F - 16 layers
E - 16 layers
A - 4 layers
C - 8 layers
D - 8 layers
B - 4 layers
Curve A B C D E F G

TABLE XVIII (Corresponding to Fig. 36).—UNSIZED CRÊPED SERVIETTE PAPER

Pressure p in kg./sq. cm.	fp.	f.
4 Layers, Curve A.		
4	0·42	0·105
8	0·80	0·100
12	1·13	0·094
16	1·43	0·090
4 Layers, Curve B.		
4	0·31	0·077
8	0·43	0·054
12	0·60	0·050
16	0·75	0·047
20	0·79	0·040
24	0·91	0·038
8 Layers, Curve C.		
4	0·35	0·088
8	0·58	0·072
12	0·91	0·076
16	1·14	0·071
20	1·47	0·074
24	1·80	0·075
28	1·95	0·070
8 Layers, Curve D.		
4	0·33	0·083
8	0·42	0·052
12	0·58	0·048
16	0·67	0·042
20	0·80	0·040
24	1·00	0·042
28	1·18	0·042
32	1·15	0·036
36	1·29	0·036
40	1·33	0·033
44	1·44	0·033
16 Layers, Curve E		
4	0·58	0·111
8	0·91	0·111
12	1·02	0·085
16	1·13	0·071
20	1·36	0·068
24	1·52	0·063
28	1·74	0·062
32	2·02	0·063
36	2·23	0·062
40	2·55	0·061
16 Layers, Curve F.		
4	0·46	0·115
8	0·80	0·100
12	1·07	0·089
16	1·25	0·078
20	1·55	0·079
24	1·80	0·075
28	2·02	0·072
32	2·09	0·065
36	2·29	0·063
40	2·38	0·060
44	2·50	0·057
48	2·45	0·051
52	2·50	0·048
56	2·50	0·045
60	2·83	0·047
64	2·62	0·041
68	2·86	0·042
72	3·05	0·042
76	3·11	0·041
80	3·33	0·042

TABLE XVIII.—*continued*

Pressure p in kg./sq. cm.	fp.	f.	Pressure p in kg./sq. cm.	fp.	f.
32 Layers, Curve G.					
4	0·69	0·172	56	3·25	0·058
8	0·91	0·114	60	3·20	0·053
12	1·09	0·091	64	3·27	0·051
16	1·58	0·099	68	3·45	0·051
20	2·02	0·101	72	3·55	0·049
24	2·11	0·088	76	3·80	0·050
28	2·19	0·078	80	4·28	0·053
32	2·17	0·068	84	4·50	0·053
36	2·34	0·065	88	4·45	0·051
40	2·34	0·059	92	4·80	0·052
44	2·47	0·056	96	4·90	0·051
48	2·76	0·057	100	4·95	0·050
52	2·96	0·057			

become compacted, but retained its loose structure. The characteristic curves are illustrated in Fig. 36, and show the variation of the coefficient f with increasing pressure as well as the variation of the force fp with the pressure.

One would have expected to find that the higher the speed, the smaller would be the value of the coefficient f; but looking at Tables XVIII., XIX., and XX. it will be seen that this expectation is only realised fully in the case of loosely felted stuff. Even then at the lowest pressure (1-2 kg. per sq. cm.) the value of f was often fairly high (0·17-0·20). For the purpose of friction tests which are intended to imitate as closely as possible the conditions in the beater, it is, therefore, essential to work only with loosely felted stuff; because the closely felted structure of a sheet of paper, even if

unsized, is not abraded and torn in a manner corresponding to beater stuff.

TABLE XIX.—UNCRÊPED SERVIETTE PAPER

Pressure p in kg./sq. cm.	fp	f.	Pressure p in kg./sq. cm.	fp.	f.
4 Layers.			16 Layers.		
4	0·85	0·212	4	0·97	0·260
8	1·09	0·139	8	2·76	0·350
12	1·13	0·091	12	3·85- 4·50	0·321-0·376
			16	4·28- 5·76	0·268-0·360
			20	5·76- 7·07	0·288-0·353
8 Layers.			24	4·55- 8·62	0·190-0·359
			28	6·50- 7·30	0·232-0·262
			32	4·95-10·41	0·155-0·325
4	0·69	0·172			
8	1·02	0·128	32 Layers.		
12	2·13	0·178			
16	2·18-4·72	0·136-0·265			
20	2·60-4·75	0·130-0·237			
24	3·67-5·76	0·153-0·240	32	about 10·0	about 0·31
28	3·25-6·90	0·116-0·245	36	...	...

TABLE XX.—BLEACHED SULPHITE PULP IN THE FORM OF BOARD

Pressure p in kg./sq.cm.	fp.	f.
4	0·80	0·200
14	3·25- 3·67	0·032-0·262
24	2·60- 5·76	0·108-0·240
34	5·36- 9·20	0·158-0·272
44	5·16-10·20	0·117-0·232

The force fp which was measured in the experiments with the crêped serviette papers should, therefore, be characterised as a tearing force and not as a frictional force; and the coefficient f in this case becomes a tearing coefficient.

Fig. 36 shows that as the pressure rises so the tearing force also increases: the layer of stuff gets forced into the depressions in the surface of the pulley, thus causing the tearing effect to be increased and the power consumption to rise.

The same curves also show that the increase in power consumption does not take place steadily, but that it rises periodically. Thus, for example, in curves F and G the tearing force remains constant at 2-2·5 kg. over a fairly wide zone. It is only when the pressure exceeds about 40 kg. per sq. cm. that the layer of stuff begins to become compacted and to offer somewhat greater resistance. The curves for f and fp as functions of p are, therefore, discontinuous, and f always diminishes as the pressure increases. Seeing that the value of f is neither constant nor a simple function of the pressure, it is unreasonable to deal with it throughout as a coefficient for purposes of calculation. In future we shall, therefore, refer only to the tearing force per square centimetre and not to the tearing coefficient.

It was also found desirable to investigate whether other raw materials would yield similar results. A fresh series of experiments was, therefore, carried out with pieces of sulphate pulp board, cotton filter paper, and paper made from linen and cotton. None of these samples of paper, however, was in a sufficiently loosely felted condition to enable a tearing action to take place as in the beater. These experiments then had to be discontinued, and the author was only able to resume them after an interval of two years; but he

was then in a position to supplement the original somewhat primitive tests and to carry out the investigations with greater thoroughness. Means also became available for examining other raw materials with greater promise of success.

The apparatus illustrated in Fig. 35 was again employed, but this time the paper samples were specially prepared with hand-made moulds. Sulphite pulp was taken from the draining chests or beaters, beaten up by hand with a large quantity of water, and thick hand-made sheets prepared from it. The sheets were couched on a felt and then lightly pressed between two felts, as far as possible under the same pressure in every case. The wet sheets produced in this way possessed just sufficient cohesion to enable small pieces to be introduced on the under surface of the friction block of the test apparatus. For the purpose of investigating the effect of the thickness of the layer of stuff, two or more layers of samples from these sheets were employed. The sheets were of such thickness that ten layers under a pressure of

4 kg. per sq. cm. yielded a thickness of 2-3 mm.
44 ,, ,, ,, 1·3-2 mm.; and
84 ,, ,, ,, 1-1·7 mm.

Samples prepared in the manner just described were found to be in a suitable loosely felted condition for the work; and a long series of experiments was carried out with them. Sheets were hand-made from the following materials:—

Linen half-stuff.
Cotton half-stuff.
Cotton whole stuff.
Bleached sulphite pulp.
Finished beaten bleached sulphite (whole stuff).

The results are shown in Figs. 37 to 41.

Two pulleys were used in the experiments, both made of steel and revolving at a speed of about 9 m.

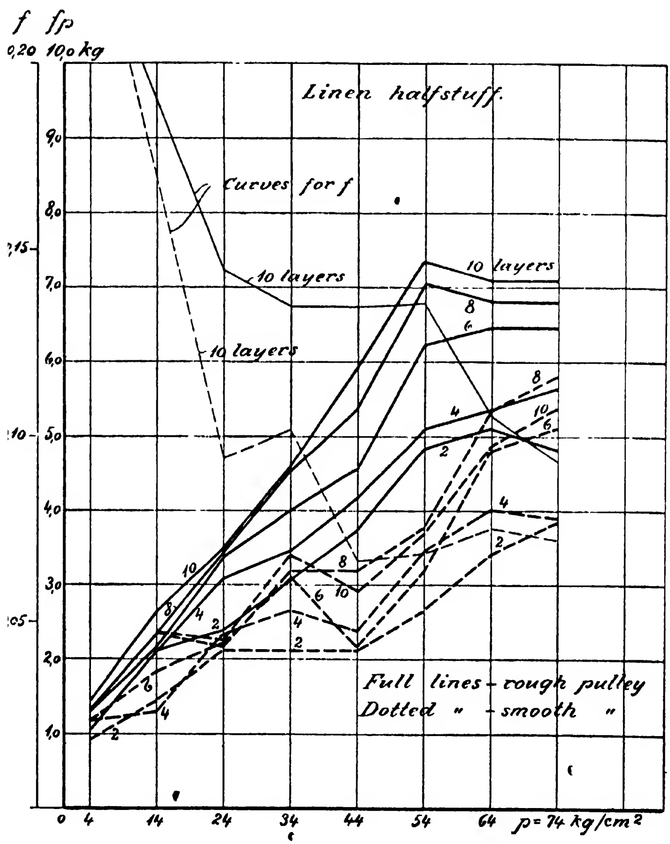


FIG. 37.

per second. One of the pulleys was gone over with a coarse file so as to give it a thoroughly rough surface and the experimental results for this pulley are indicated in the figures by continuous lines. The other pulley

was smooth polished, and the results which it gave are indicated by the dotted lines. Each series of tests was carried out with various numbers of layers (2, 4, 6, 8, and 10), and for each different number of layers a curve was drawn showing the relation between the tearing force and the pressure.

One of the first points to be observed during the experiments was that the rate at which tearing took place invariably increased with increase in tearing force. It is, therefore, possible to formulate the rule that the greater the tearing force in the beater the more intensive will its action be. The output will, therefore, rise steadily with the tearing force.

The torn stuff was flung freely off the pulley; and in some cases was caught on a glass plate for microscopic examination. It was found that in the case of eight layers of sulphite which had been subjected to a pressure of 4 kg. per sq. cm. the stuff had become very "wet," and some cellulose mucilage and lacerated fibres were observed in addition to a few pieces of fibre in a more or less well preserved condition. On the other hand, the same number of layers of sulphite (eight) tested under 84 kg. per sq. cm. pressure were transformed into a slimy mass from which every trace of the original fibrous structure had disappeared. The same experiments were attempted with two layers of sulphite, but presented considerable difficulty owing to the stuff being rapidly shredded into small pieces, so that no real beating took place.

The following further conclusions were drawn from the results of the experiments :—

The rougher the surface of the pulley, the greater was the tearing force and the more rapidly the layer of stuff was abraded.

The tearing force is greater for half-stuff than for

the corresponding whole stuff, and greater for rags than for sulphite, using the same surface of pulley in every case.

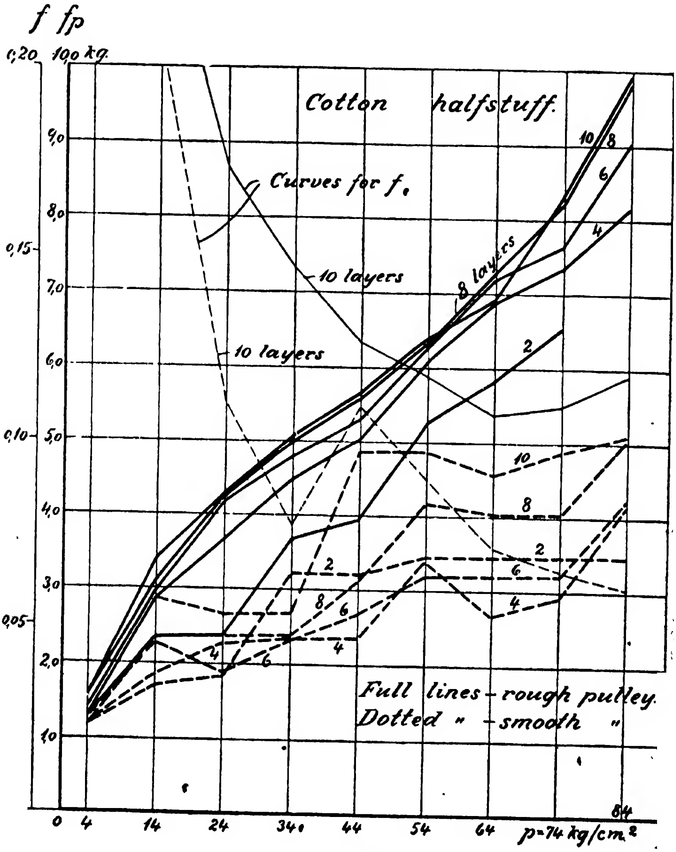


FIG. 38.

The original moisture content of the sample affects the magnitude of the tearing force such that the latter is greater where the stuff is comparatively dry, and

diminishes somewhat if the stuff contains much water.

The tearing force is smallest with a thin layer of stuff and increases quickly with increase in the thickness up to eight to ten sheets. Beyond this point the effect of the thickness ceases.

This may be explained by the fact that great thickness results in a more uniform distribution of stuff on the pulley. This causes stuff to be forced into every minute depression in the surface of the pulley, thus producing a more intensive tearing action and increasing the force required to produce it. An exception to this rule was found in the case of cotton half-stuff in which the tearing force for two sheets in a layer was greater than that for four sheets.

It will be remarked that the discontinuity of the curves relating to the original experiments reappears in the case of most of the new curves. It is seen most clearly in the curves appertaining to cotton whole stuff and linen half-stuff. In the latter curves the tearing force becomes constant, or even diminishes with increasing pressure. In this connection the experiments have shown that the discontinuity is most marked with thin layers of stuff and particularly where for any reason the surface of the pulley has become slightly less rough. In the diagram (Fig. 39) for cotton whole stuff, the curves for three, four, and five layers diverge considerably from the approximately straight line which is the characteristic form of curve for greater thicknesses of stuff. The smoother the surface of the pulley, the earlier the curves will commence to diverge from the straight line characteristic; and a complete series of intermediate shapes can be plotted down to the limiting curve for the smooth polished pulley.

Each sheet of curves also contains two curves which

illustrate the variation of the coefficient f; and in which the curious discontinuity can be detected although it

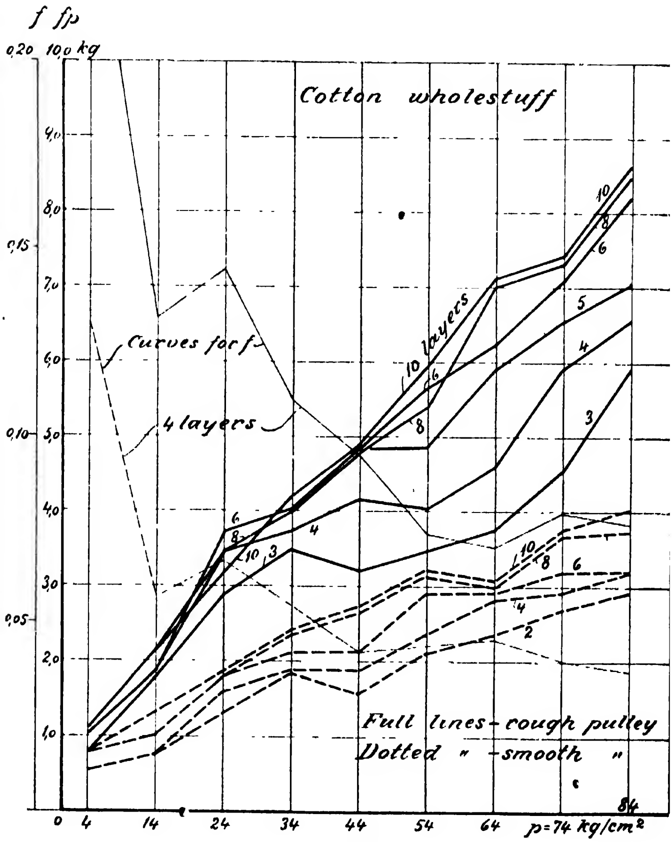


FIG. 39.

is not so marked as in the fp curves. In the experiments with the smooth polished pulley practically no tearing of the stuff could be observed to take place, and the coefficient f under these circumstances must be regarded

as a coefficient of friction. The dotted *fp* curves for the smooth polished pulley only ascend slowly or not at all, and the coefficient of friction, therefore, diminishes rapidly with increasing pressure. This may be explained by the fact that even an increase in pressure cannot bring the fibres into more intimate contact with the smooth surface of the pulley; and it will be noted that the curves for unbeaten sulphite half-stuff practically do not ascend at all.

All the remaining stuffs contained a greater or less quantity of small fibrillæ, which with increasing pressure were caught and torn away by the minutely fine grooves in the surface of the polished pulley. For these materials slightly ascending curves were, therefore, obtained.

From experiments carried out with oil and dead-beaten stuff, Schubert has concluded that the minimum possible coefficient of friction between half-stuffs and the bar surfaces of beating tackle is 0·092. It will be seen from what has already been said that this conclusion must be erroneous. The coefficient of friction usually has a much lower value, being about 0·02 to 0·04 for the range of conditions with which we have been dealing. Even the tearing coefficient is less than 0·092 providing the pressure is not too low. Schubert has also produced curves showing the variation of the beating coefficient μ with different pressures, obtained by measuring the power consumptions (in beating various raw materials). He remarks in this connection that "the curves obtained from the values of μ tend to flatten off to a constant value at a beating pressure which depends on the nature of the half-stuff." This constant value Schubert terms the "specific beating coefficient" for the particular half-stuff. The experimental data now submitted by the author show that this process of thought cannot be correct: for any given

material there can neither be a characteristic nor a specific beating coefficient.

Notwithstanding his incorrect conclusions, Schubert's investigations are of great scientific interest, and the author has taken the liberty of reproducing a few of

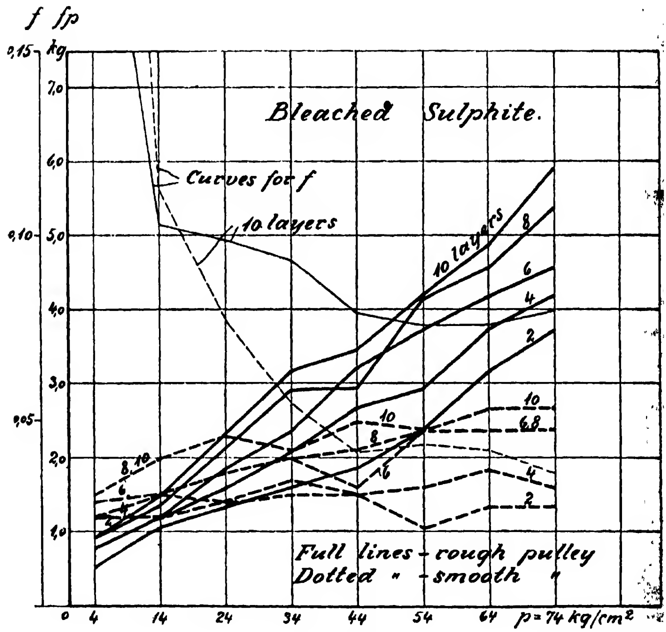


FIG. 40.

Schubert's curves (see Fig. 26 A-E) modified to suit the co-ordinate system adopted in the present work.

All the author's fp curves embody an error of observation, inasmuch as the points corresponding to the lowest pressures all lie slightly too high. In reality the curves should descend rather more steeply at quite low pressures than is shown (as may also be deduced

from Schubert's curves). The reason is that in order for the samples of stuff to be retained firmly between the block and the pulley it was necessary to make them a little larger than the lower surface of the block. A certain amount of adhesion was thus created between

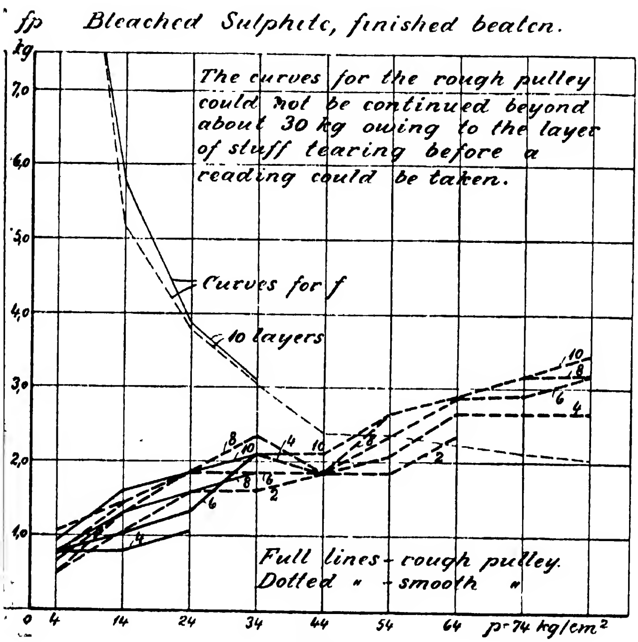


FIG. 41.

the overlapping portion of the sample and the surface of the pulley. This produced an additional braking effect on the pulley such that the lowest observed values were from 25 to 50 per cent. too high.

Looking at the results of the tearing experiments as a whole, a marked similarity will be noticed between the beating operation in the Beater and the tearing

phenomena under investigation. The following are a few of the points of resemblance :—

(1) Rag half-stuff requires more power for tearing than rag whole stuff—exactly as in the beater.

(2) Sulphite cannot withstand as high a tearing pressure (beating pressure) as rags. (The tests with sulphite whole stuff could only be carried out up to a pressure of about 30 kg. per sq. cm.)

(3) Sulphite was found to tear asunder best in a thick layer—just as in the beater it works best at a thick consistency.

(4) The general shape of the curves is similar to that of the corresponding curves which were drawn for the specific power consumption of the beater.

All these factors point to a close analogy between the tearing process which has just been investigated and the tearing process in the beater, so that it should be possible to apply to the conditions in the beater the experience gained from the tearing experiments.

We shall now try to make use of the above conclusions for the purpose of analysing the specific power consumption of the beater.

Equation (23*a*) reads :—

$$\mu = fp_k + \frac{e}{100(s_r + s_r)}.$$

If the cutting resistance e is sufficiently small to be able to be neglected, then since

$$p_k = \frac{1}{\eta} p \qquad - \quad - \quad - \quad - \quad (14a)$$

we may rewrite equation (23*a*) as follows :—

$$\mu = \frac{1}{\eta} \cdot fp.$$

Under these circumstances it therefore follows that the $\bar{\mu}$-p_k curve could be derived from the fp-p curve

by simply altering the scales of the co-ordinates, *i.e.*, by dividing these scales by η. For example, with $\eta = 10$, a pressure of 84 kg. per sq. cm. on the fp-p curves would correspond to an edge pressure of 8·4 kg. per cm. on the $\bar{\mu}$-p_k curves; and a tearing force of 6 kg. per sq. cm. in the fp-p curves would correspond to a specific power consumption of 0·6 m.-kg. per square decimetre of beating surface per second.

If the tearing curves are compared with the curves for the specific power consumption, it would actually appear feasible to make these two sets of curves almost coincide with one another merely by altering the scales of the co-ordinates. It is, therefore, reasonable to conclude that the value of the term containing e will generally have only a minor effect on the value of the specific power consumption.

Thus, for example, with $\eta = 10$, the $\bar{\mu}$ curve (Fig. 25C) for beating rags corresponds exactly with the tearing curve for cotton (Fig. 38) and is only slightly higher than the corresponding curve in Fig. 39. With a similar value of η, the $\bar{\mu}$ curves in Figs. 25B and E, for edge pressures up to about 3·5 kg., coincide very closely with the tearing curves for thick layers (Figs. 41 and 40).

As the edge pressure increases above this value, so the $\bar{\mu}$ curves ascend much more steeply than the tearing curves would lead one to anticipate. This is, however, quite natural, for the beating pressure will then have become so high that the fibrages are almost severed, with the result that not only is a considerable cutting resistance introduced, but at the maximum edge pressure there will also be direct contact and, therefore, friction between the actual metallic surfaces ($f = 0·17$). Referring to the two curves marked A in Fig. 25E, the lower one represents readings taken after twenty minutes, while the readings for the upper curve were taken with

finished beaten stuff after $4\frac{3}{4}$ hours beating time. They indicate that towards the end of the beating operation the fibrages are much more easily severed or torn than on commencing to beat. The readings for curves C and B in the same figure were taken after $3\frac{1}{4}$ and $6\frac{1}{4}$ hours of beating respectively.

The μ curves in Figs. 25A and E refer to experiments carried out with Kraft pulp in beater MIII3. The curves in Fig. 25D together with curve A in Fig. 25A were obtained with 8 mm. bedplate bars and curve B in Fig. 25A with 14 mm. bedplate bars. For $\eta < 10$, the curves obtained with the thin bedplate bars correspond exactly with the tearing curves for sulphite in thick layers (Fig. 41). On the other hand, curve B in Fig. 25A is of a shape which is characteristic when the layer of stuff is too thin in comparison with the intensity of the tearing action which it is called upon to withstand.

The foregoing examples show that useful information concerning the working conditions can be derived by systematically plotting curves for the specific power consumption of a beater at various pressures and various consistencies and comparing these curves with the tearing curves. As far as the author is aware, systematic tests of this nature have not yet been carried out for the ordinary range of consistencies met with in practice (4 to 8 per cent.). Schubert's results are the only ones available, and they only apply to consistencies up to 4 per cent. and to edge pressures up to 1 kg. The effect of the resistance to cutting can be clearly seen from these experiments: all the curves for 1 per cent. consistency are above those for 4 per cent. consistency, whereas according to the tearing curves one would expect to find lower values. The explanation is that at 1 per cent. consistency the cutting resistance is greater than at 4 per cent.

Unfortunately, it is fundamentally impossible to analyse the specific power consumption with exactitude owing to the fact that equation (23*a*) contains two terms η and e which cannot be directly measured. It is, therefore, an equation with two unknowns and necessitates resort in some measure to estimation.

CHAPTER IV

THE POWER CONSUMPTION FOR ROTATING THE ROLL IN THE STUFF

IT has been seen from equation (18a) how to determine the amount of power (N_R) absorbed in rotating the roll in the stuff when it is raised clear of the bedplate. Moreover, it was pointed out that this power is partly consumed by the whipping of the flybars against the circulating stuff, and partly absorbed in friction losses in the stuff. We shall now proceed to investigate this portion of the total power consumption of the beater.

The power consumed in the whipping of the bars on the stuff has been investigated so frequently[1] that it is almost impossible to add anything new. The stuff approaches the roll quite slowly in an approximately horizontal direction and is then suddenly compelled to take part in the motion of the flybars. In addition to this, if the backfall is incorrectly designed, it is possible for a further quantity of stuff to enter the cells on the backfall side of the bedplate, in which case there will be still more stuff subjected to the whipping action. Finally, even in the best beaters, a certain amount of stuff will always be carried right round by the roll (spitting). Presumably this stuff in its passage over the top of the roll will be flung against the interior surface of the hood several times prior to dropping down in front of the roll and being caught up by the flybars

[1] Kirchner, "Das Papier. IV., Ganzstoffe," p. 13; and Pfarr, "Hollaender und deren Kraftverbrauch," reprint, p. 15.

again (see Fig. 42). Thus this portion of the stuff will be subjected to the whipping action repeatedly.

It may be assumed that the blows or impacts of the flybars on the stuff are in the nature of impacts between inelastic bodies (the stuff may be compared to lumps of clay). The energy absorbed on impact or the work done on impact will then be proportional to the square

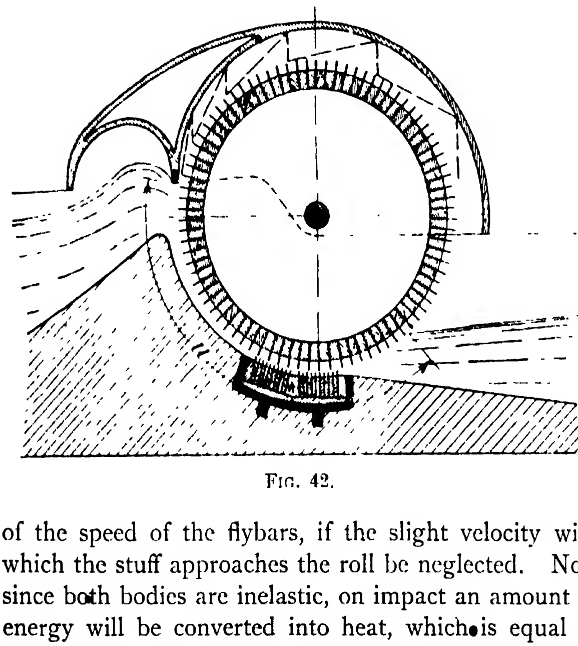


Fig. 42.

of the speed of the flybars, if the slight velocity with which the stuff approaches the roll be neglected. Now since both bodies are inelastic, on impact an amount of energy will be converted into heat, which is equal to the kinetic energy still possessed by the flybars after impact. Therefore, if 1 kilo of stuff enters the cells, the amount of energy consumed in whipping this quantity of stuff will be

$$2 \cdot \frac{v^2}{2g} \text{ metre-kilograms,}$$

where g is the acceleration due to gravity.

The letter G will now be used to denote the number of kilos of stuff which flow through any given cross section of the trough in one second. This quantity can be determined with some degree of accuracy for a portion of the trough remote from the roll, if the dimensions of the cross section are known and a stick inserted perpendicularly in the stuff. The speed of the stick will be the same as the speed of the stuff, assuming the travel to be uniform over the whole of the cross section. (It will nearly always be found that the stick retains its vertical position, thus showing that there can be no appreciable difference between the speed of the stuff at the top of the cross section and that at the bottom.) This holds good for the average range of consistencies and provided the interior surface of the trough is not too rough or corroded. One would accordingly be inclined to think that the power consumed by the flybars in striking the stuff (whipping) should be given by $G.\frac{v^2}{g}$. In point of fact, however, the power consumption will be greater, because one portion of the stuff in traversing the roll will be struck two or more times, while a certain quantity of stuff will not circulate round the trough, but will pass right over the roll and will also be struck several times. The expression for the power absorbed in whipping will, therefore, be :—

$$C.G.\frac{v^2}{g} \text{ m.-kg. per sec.,}$$

where C is a coefficient (greater than 1) the value of which depends on the shape of the backfall and the effectiveness of the doctor.

It was formerly thought that the amount of stuff (G) transported per second by the roll increases with the speed of the flybars. This is not the case. In all

beaters met with under industrial conditions, the transporting capacity of the roll is far in excess of the rate of flow of the stuff round the trough. The latter is only affected to a small extent by the speed of the roll [1] and is chiefly influenced by the height of the backfall, the smoothness of the interior surface and shape of the trough, the slope of the trough floor, and by the consistency of the stuff. As soon as the stuff reaches the crown of the backfall it moves, under the pressure of the freshly arriving stuff, as a composite mass, following the slope of the floor until the roll is reached again. Without a backfall it is, therefore, impossible to produce circulation of the stuff (in the ordinary hollander). The motion of the stuff is not in the nature of a flow in the ordinary sense of the word. It may perhaps be compared best with the valleyward movement of a glacier under the pressure of the upper masses of ice.

We now come to consider that portion of the power consumption which is due to friction losses in the stuff. It will be necessary to investigate this question rather more closely than the previous one, because erroneous ideas are still generally prevalent in connection with the internal friction of beater stuff. All the workers who have so far been engaged in investigating the matter have started with the assumption that stuff may be regarded as a liquid, and have made use of the laws governing the flow of liquids.[2] On this basis the friction is found to be proportional to the square of the speed and the power absorbed in friction to the cube of the speed. These results correspond to the laws

[1] Kirchner arrived at the same conclusion in his investigations, "Das Papier. IV., Ganzstoffe," p. 224.

[2] Pfarr, "Hollaender und deren Kraftverbrauch," reprint, p. 17; Haussner, "Der Hollaender," p. 9; Kirchner, "Das Papier. IV., Ganzstoffe," p. 231.

governing the frictional resistance of ships and the flow of water through pipes.

It must not be forgotten, however, that these laws only hold as long as true liquids are being dealt with. Before applying them to the beater it is first necessary to examine whether the stuff actually behaves in a similar manner to a liquid. The chief properties of liquids will, therefore, first be enumerated and it will then remain to be determined whether stuff of the usual range of consistencies (say 5 to 10 per cent.) possesses the same characteristics.

A liquid may be defined as a body the particles of which become displaced relatively to one another under the influence of even the smallest forces ; notwithstanding the fact that there is a certain amount of friction between the individual particles. Moreover, according to Maxwell, if one layer of a liquid is moved relatively to another and parallel layer, then the friction between the two layers is independent of the pressure (contrary to solid bodies), but is proportional to the area of the surface and to the difference between the velocities of the two layers. Successive layers of a liquid may, therefore, possess different velocities, and the velocity of any individual particle will depend on its distance from the boundary surfaces of the moving layer to which it belongs.

The fact that beater stuff can retain a sloping free surface is already sufficient to demonstrate that it does not fall within the definition of a liquid. Even if stuff is allowed to stand in a beater for twelve or twenty-four hours its surface may not become perfectly horizontal. A certain minimum of effort [1] is, therefore, required

[1] Eichhorn reports in one of his tests that a spanner weighing 11 lbs. remained on top of the stuff in the beater without sinking in more than half-an-inch.

in order to produce relative movement between the particles of stuff. The resistance to this movement does not, however, decrease to zero when the relative velocities approach zero. It is, therefore, impossible for the laws governing the internal friction (viscosity) of liquids to apply to the stuff in the beater; for these laws lay down that the friction is proportional to the difference in velocities. Beater stuff, therefore, cannot be regarded as a liquid, and it is incorrect to apply to the beater such formulæ as Froude's for the resistance of ships or those for the flow of liquids through pipes.

By carefully observing the behaviour of moderately thick stuff in the beater the impression is obtained that a considerable amount of internal friction is at work. The stuff "rolls" round the trough in a characteristically turgid manner. The friction against the sides of the trough is obviously less than the internal friction of the stuff itself, and only where the surfaces of the trough are specially rough or corroded is the friction against them sufficient to disturb slightly the adjacent portions of stuff.

If the laws covering the behaviour of liquids were applicable to stuff, it would mean that there would exist in the beater conditions of flow similar to those in a liquid moving faster than its critical velocity. That is to say, the speed of the stuff would increase towards the centre of the stream, and there would be an eddy motion (in these circumstances the resistance is approximately proportional to the square of the velocity). Such conditions of motion, however, do not obtain in the beater.

A simple experiment will explain the matter still more clearly. If a coloured straight line is painted square across the surface of the stuff at the upper end

of the open side of an ordinary beater trough, it will be found that when this portion of the stuff has reached the lower end of the same side of the trough, the coloured straight line is still straight and still at right angles to the sides of the trough. This experiment and the one already referred to with the upright stick inserted in the stuff, together show that the velocity of the stuff is very nearly constant over the whole of its cross section. No internal movements take place in the stuff other than those naturally produced by the curvatures and contractions of the trough. The motion of the stuff does not even resemble the flow of a liquid at less than its critical velocity (where the resistance is proportional to the speed), for even under these conditions of flow the particles in the centre of the liquid stream would travel more rapidly than those at the sides.

At the points of curvature, or where the stuff is in juxtaposition to the roll, it certainly is possible for cleavage surfaces to be formed, and a sliding action then occurs. It is also well known that so-called dead spots are liable to be formed where a portion of the stuff remains stationary and does not circulate while the remainder of the stuff flows by. The friction between the stationary and the moving surfaces, however, does not appear to produce any internal motion in the stuff, and it must, therefore, be assumed that the force necessary to overcome the frictional resistance between two layers of stuff is independent of the relative speeds of the layers. If the frictional resistance diminished with the speed, then as the speed was reduced one would expect to find some internal motion in the stuff.

There would thus appear to be some ground for the following assumptions :—

1. That the internal friction of the stuff in the beater is independent of any difference in the speeds

of different portions of it (similar to the case of solid bodies).

2. That the friction between two surfaces of cleavage is independent of the pressure between them, so that an increase in pressure does not bring the particles forming the two surfaces into more intimate contact with one another (corresponding to the friction in liquids).

3. That the friction is proportional to the area of the surface at which friction occurs (corresponding to the friction in liquids).

We thus are called upon to deal with a special kind of friction, the unit of which may be described as the force (in kilograms) required to move one layer of stuff over an adjacent layer, the area of the surface of cleavage being 1 sq. m. (coefficient of friction of a pulpy mass).[1]

It is possible to investigate the truth of the above assumptions by means of experimental apparatus comprising a beater roll fitted into a tall, enclosed casing, stuffing boxes being provided at the points where the shaft emerges from the casing. The roll is driven by a variable speed motor. If the casing is filled with pulp up to above the level of the top of the roll, the power required to drive the roll can be measured at various speeds and various pressures. Care must, of course, be taken that the cells are actually filled with stuff. Such experiments are very troublesome to carry out, and were for this reason omitted from the present work.

Observations were, however, obtained with the aid

[1] This unit possesses the same dimensions as cohesion; but the phenomenon differs from cohesion in that the latter operates in the main up to the point where motion commences, whereas the internal friction in a pulpy mass occurs during motion.

of the simpler apparatus illustrated in Figs. 43 and 44, consisting of two wooden "boats." Each boat was

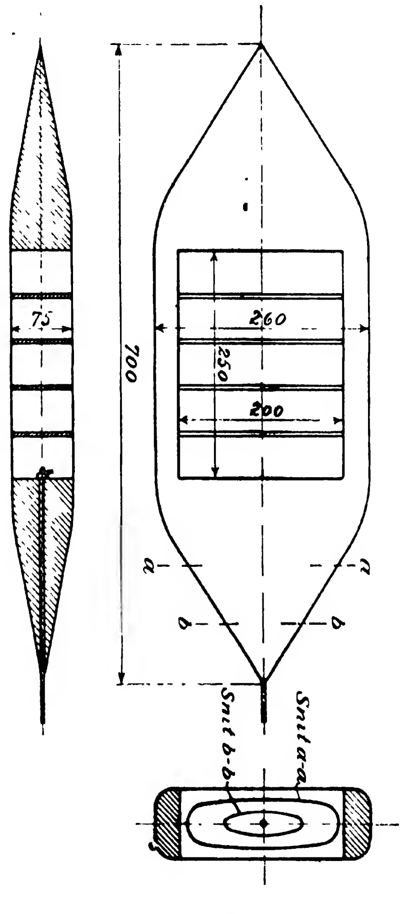


FIG. 43.

weighted with sufficient shot to make it weigh 1·02 times as much as the volume of water which it displaced

on immersion. The specific gravity of the beater stuff also being 1·02, it followed that the boats when immersed in stuff tended to remain in equilibrium. The wood was well varnished so as to avoid any possible change of weight due to absorption of water. A rectangular hole (0·20 × 0·25 m.) was formed in one of the boats and fitted with sheet metal cross strips as shown in Fig. 43. This boat was thrust down into a

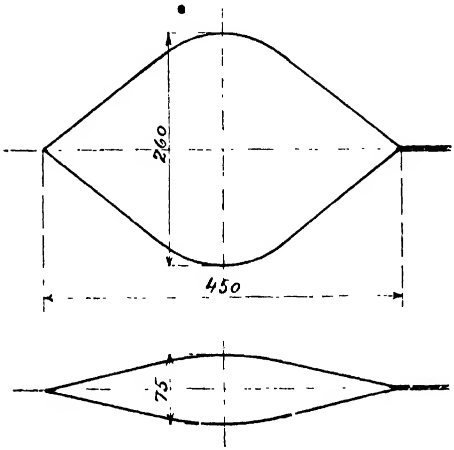


FIG. 44.

beater in such a way that the hole was filled with stuff; and with the aid of a spring balance it was then dragged through the stuff. The spring balance registered the total resistance to movement. This resistance was partly due to the fact that the boat had to cleave for itself a passage through the stuff, and partly to the internal friction of the stuff acting over an area of $2 \times 0{\cdot}20 \times 0{\cdot}25 = 0{\cdot}1$ sq. m.

The boat without the hole (Fig. 44) was used to

TABLE XXI

	About ½ Hour after Filling			Finished Beaten Stuff.		
	a.	*b.*	ϕ kg./m.²	*a.*	*b.*	ϕ kg./m.²
Sulphite pulp :—						
5·0 per cent. consistency -	10·5-12·5	5·5-7·5	50	7-9	3-4	40-50
5·2 ,, ,, -	10	6	40	6	4	20
6·6 ,, ,, -	15	10	50	15	9	60
7·2 ,, ,, -	24-28	11-14	130-140	16-18	10-12	60
Rag stuff :—						
5·5 per cent. consistency -	8	5	30	7	4	30

According to American sources it has been found possible to utilise successfully the internal friction of the stuff r the purposes of determining its beating condition. *Cf. Paper*, 1917, No. 23, A. B. Green, "Management of the eater Room."

measure the resistance due merely to the cleavage of a passage. The difference between the readings of the two boats gave the resistance due to internal friction over an area of 0·1 sq. m. It appeared that the value of this friction was quite independent of the speed at which the boat moved. The results of these experiments are shown in Table XXI., the "*a*" values having been obtained with the boat shown in Fig. 43, and the "*b*" values with that shown in Fig. 44.

It is probable that the sharp variations in the value of the coefficient of friction, which occur notably during the first stages of beating just after the beater has been filled, are partly attributable to the stuff not being thoroughly broken up and varying in consistency in different parts of the beater. It is probably also due to this that the power consumption of a beater generally fluctuates so considerably during the first half hour or so after filling.

Following what has been said above, the frictional resistance over a surface area of A sq. metres will be ϕA, and is independent of the pressure or the speed. If this surface is moved at a speed of v metres per second, then the amount of work required to overcome the frictional resistance will be ϕAv. The accuracy of the latter statement has unfortunately not been established with absolute precision; and having regard to the nature of the available experimental data exact proof is impracticable. It will be found, however, that in adopting this theory of the friction of the stuff as a basis of calculation, nothing arises which is incompatible with it; which fact tends in a measure to substantiate the truth of the theory.

In the case of the beater, which involves measuring the friction between the stuff rotating in the cells and the practically stationary stuff in the trough or backfall

pocket, the area A must be represented by that portion of the surface of the roll which is submerged in the stuff (LU), as shown in Fig. 42. For the sake of simplicity the working surfaces of the bars may be included in this area. If the stuff located in each cell were not eddying, then the difference in speeds to be considered would for all practical purposes be equal to the speed of the flybars, viz., v metres per second. On this assumption the energy consumed per second in overcoming friction would be ϕLUv metre-kilograms. In reality the conditions are not quite so simple, for, as will be seen from Fig. 7, the difference in speeds is only v_r. As against this, however, there are other frictional losses due to internal friction in the eddies and to the friction of the stuff in the cells against the surfaces of the flybars. In addition, there may be a rotary movement of stuff in the backfall pocket which will also cause friction losses.[1] It must be assumed that all these friction losses each increase in proportion to the speed of the flybars, and the total friction loss can, therefore, be expressed by $\epsilon\phi LUv$ metre-kilograms per second, where ϵ is a coefficient which is independent of the speed of the flybars.

At this point reference may be made to Haussner's experiments on the internal friction in stuff.[2] Haussner regarded the stuff as a liquid, and employed the formulæ governing the flow of liquids through pipes; but he nevertheless reached a conclusion which, to some extent, tallies with the view expressed above, namely that the internal friction is independent of the

[1] It is not necessary to take account of the friction of the end faces of the roll against the stuff; because the bangers will ensure that any stuff entering the clearance between the walls of the trough and the ends of the roll will be at once removed.

[2] Haussner, "Der Hollaender," pp. 10-38.

difference in speeds between contacting layers of stuff.

His experiments were conducted with stuff flowing through a pipe of 40 mm. bore; but could only be carried out at quite thin consistencies. Already at consistencies of 3 to 4 per cent. the effect of the pipe walls was such as to cause the stuff to form lodgments through which the water drained out. Had larger pipes been used, the stuff would no doubt have flowed through at considerably higher consistencies under the pressure which was available.

The object of the experiments was to determine the value of the coefficient of resistance ζ, which is contained in the ordinary expression for the loss of head in a pipe. This expression is as follows :—

$$h_{,} = \zeta . l \frac{u}{F} . \frac{w^2}{2g},$$

where l is the length of the pipe.

u is the length of the wetted perimeter.

F is the cross-sectional area.

w is the speed of the stuff.

$h_{,}$ is the loss of head due to the resistance of the pipe.

Notwithstanding the fact that no observations were obtained at high or even moderately high consistencies, Haussner claims to have settled that the coefficient of resistance of a pipe to the flow of stuff through it is given by the following expression :—

$$\zeta = \frac{B}{C - \rho \sqrt[4]{w}} + D,$$

where ρ is the consistency expressed in percentage, and B, C, and D are constants depending on the nature of the stuff.

In attempting to corroborate this conclusion it was found that when the stuff only travelled slowly through

the pipe the loss of head was very much greater than the value for ζ given by the above expression. Haussner compensates for this by introducing the term $\frac{A\rho^2}{w^2}$, so that the equation becomes

$$\zeta_r = \frac{A\rho^2}{w^2} + \frac{B}{C - \rho\sqrt[4]{w}} - D.$$

According to Haussner the first term $\left(\frac{A\rho^2}{w^2}\right)$ alone in this equation is the determining one when the rate of travel of the stuff is slow and the consistency fairly thick. Neglecting the last two terms and inserting the value $\zeta = \frac{A\rho^2}{w^2}$ in the formula for the resistance of a pipe to the flow of liquids, we have

$$h_r = \frac{A\rho^2}{w^2} \cdot \frac{lu}{2g}.$$

It will be seen from this that Haussner's investigations also lead to the conclusion that the pressure required to deliver stuff through a pipe is independent of the velocity, where the consistency is fairly thick. This conclusion agrees closely with that formulated by the author on the basis of the experiments with the wooden boats.

The power consumed in merely rotating the roll in the stuff is made up of the power consumption for whipping plus that for overcoming the frictional resistance between the roll and the stuff: it may, therefore, be written :—

$$N_R = \frac{1}{75}\left(\frac{CG}{g}v^2 + \epsilon\phi LUv\right) \quad - \quad - \quad - \quad (24)$$

During the course of the tests carried out with beaters with individual drive from a variable speed motor, frequent readings of the power consumption N_R

were taken at various roll speeds. The values of N_R determined in this way will now be examined with a view to confirming the truth of equation (24). This can best be done graphically and by employing a fresh variable $T = \frac{75N_R}{v}$ in place of the variable N_R. It should be noted that T will now represent the total resistance offered by the stuff to the rotation of the roll, if this resistance be imagined in the form of a force acting tangentially to the surface of the roll. Substituting T for N_R in equation (24) we then get

$$T = \frac{CG}{g}v + \epsilon\phi LU \qquad - \quad - \quad - (24a)$$

in which T is expressed as a function of v. This is the equation to a straight line originating at a point $T_o = \epsilon\phi LU$ distant from the T-axis, and having a slope $\tan\beta = \frac{CG}{g}$, β being the angle between the straight line and the v-axis. The equation may, therefore, be simplified and written as follows :—

$$T = v\tan\beta + T_o \qquad - \quad - \quad - (24b)$$

For the purpose of investigating the experimental results, the values found for T at various roll speeds v are plotted and a straight line drawn through them in each case. The values of T_o and $\tan\beta$ can then be measured direct from these graphs. If now the amount of stuff (G) transported per second and the internal coefficient of friction ϕ have been determined previously to taking the power consumption readings, then it is quite simple to find the values of C and ϵ respectively from the equations :—

$$C = \frac{g \tan\beta}{G} \qquad (25)$$

and

$$\epsilon = \frac{T_o}{\phi LU} \qquad (26)$$

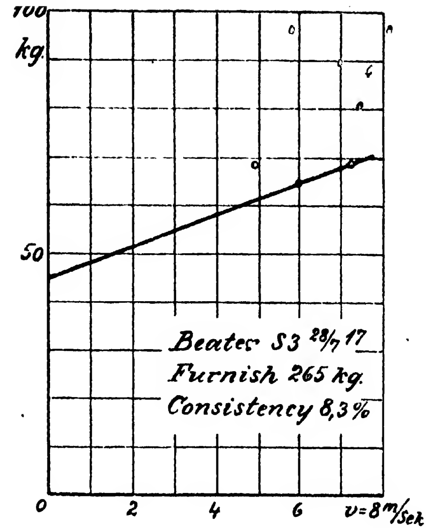
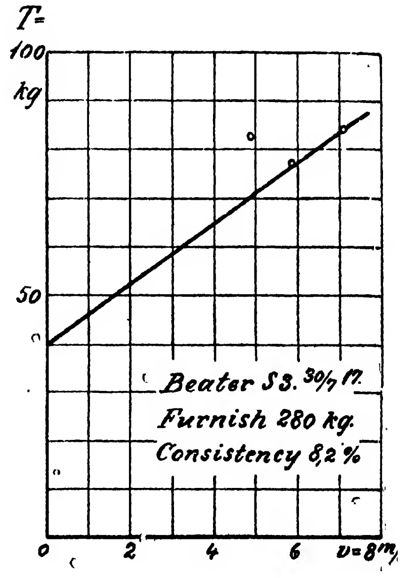

100
kg
50
Beater S3 28/7 17
Furnish 265 kg.
Consistency 8,3 %
0
2
4
6
v=8 m/Sek

FIG. 45A.


T=
100
kg
50
Beater S3. 30/7 17.
Furnish 280 kg.
Consistency 8,2 %
0
2
4
6
v=8 m/

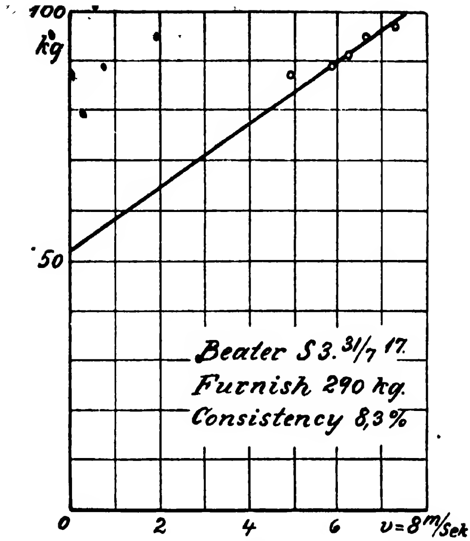


FIG. 45C.

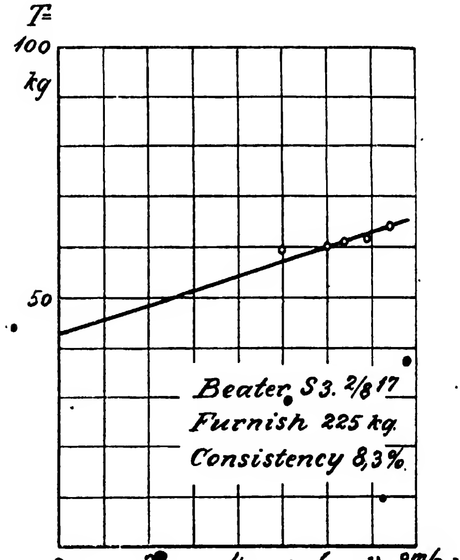


FIG. 45D.

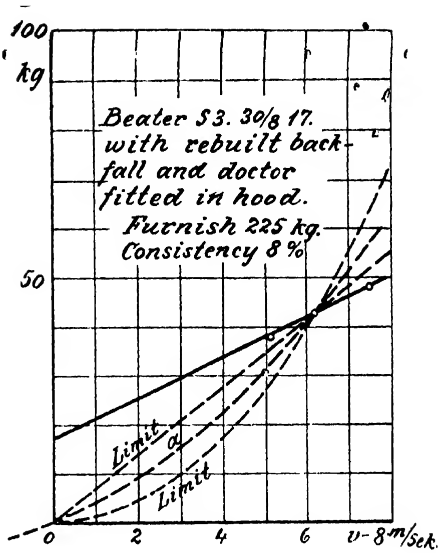
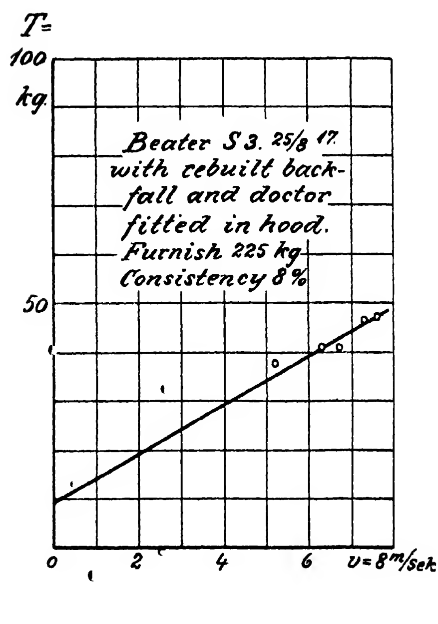

100
kg
Beater S 3. 30/8 17.
with rebuilt back-
fall and doctor
fitted in hood.
Furnish 225 kg.
Consistency 8 %
50
Limit
a
Limit
0
2
4
6
v-8 m/Sek.

FIG. 45E.


T=
100
kg.
Beater S 3. 25/8 17.
with rebuilt back-
fall and doctor
fitted in hood.
Furnish 225 kg
Consistency 8 %
50
0
2
4
6
v=8 m/sek.

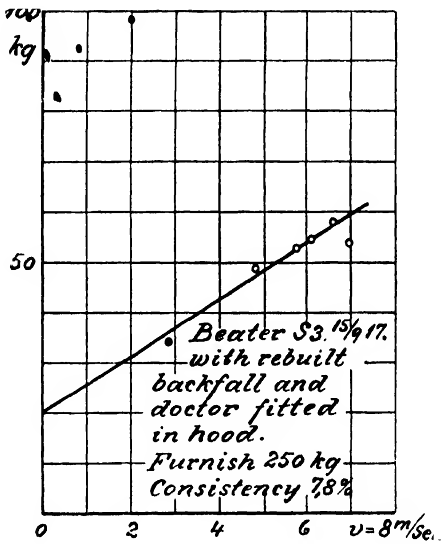


FIG 45G.

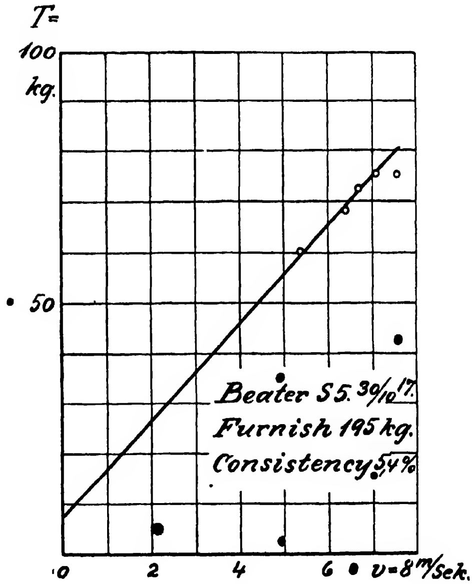


FIG 45H

TABLE XXII. (see Figs. 45A-D).—BEATER NO. S3 WITH SULPHITE

Date.	Furnish, Q.	Consistency.	N_R	v	T	U	LU	tan β.	T_c	CG = 9·81 tan β.	$\epsilon\phi = \frac{T_c}{LU}$	Fig.	Remarks.
	kg.	Per cent.	H.P.	m./sec.	kg.	m.	m.^{2}		kg.	kg./sec.	kg./m.^{2}		
28/7	265	8·3	6·7 5·2 4·5	7·25 6·0 4·9	69 65 69	1·73	1·47	3·2	45	32	30	54A	No wedge-shaped doctor was fitted to the hood. The width of the back-fall pocket was 50-60 mm.
30/7	280	8·2	8·0 6·0 5·4	7·1 5·9 4·9	84 77 82·5	1·73	1·47	6·2	40	61	27	45B	
31/7	290	8·3	5·7 7·0 7·6 8·5 9·5	4·9 5·9 6·25 6·25 7·3	87 89 91 95 97	1·85	1·57	6·4	52	63	33	45C	
	225	8·3	6·3 5·6 5·2 4·8 3·9	7·4 6·9 6·4 6·0 5·0	64 61·5 61 60 59	1·60	1·63	2·8	43	28	32	45D	

TABLE XXIII. (see Figs. 45E-G).—BEATER NO. S3 WITH SULPHITE

Date.	Furnish, Q.	Consistency.	N_R	v	T	U	LU	tan β.	T.	CG = 9·81 tan β.	$\epsilon\phi = \frac{LU}{T_o}$	Fig.	Remarks.
	kg.	Per cent.	H.P.	m./sec.	kg.	m. rd.	m.²		kg.	kg./sec.	kg./m.²		
30/8	225	8·0	2·6 3·5 4·8	5·1 6·2 7·5	38 43 48	1·60	1·36	4·2	17	41	12·5	45E	A doctor was fitted in the hood as shown in Fig. 42. The width of the backfall pocket was reduced from 50-60 mm. to 10 mm.
25/8	225	8·0	4·8 4·5 3·65 3·5 2·65	7·6 7·3 6·7 6·3 5·2	47 46·5 41 41 38	1·60	1·36	5·0	9	49	6·6	45F	
15/9	250	7·8	5·0 5·05 4·5 4·1 3·1	6·95 6·6 6·15 5·8 4·8	54 58 54·5 53 49	1·60	1·36	5·6	20	55	14·7	45G	

TABLE XXIV. (see Fig. 45H).—BEATER NO. S5 WITH SULPHITE

Date.	Furnish, Q.	Consistency Per cent.	N_R	v	T	U	LU	tan β.	T_o	$CG = 9{\cdot}81 \tan\beta$.	$\epsilon\phi = \frac{LU}{T_o}$	Fig.
	kg.		H.P.	m./sec.	kg.	m.	m.²		kg.	kg./sec.	kg./m.²	
30/10	195	5·4	7·6 7·1 6·5 5·8 4·3	7·55 7·1 6·7 6·4 5·4	75 75 72 68 60	ca 1·35	1·08	9·5	7·5	9·3	7	45H

The values found experimentally are shown in Tables XXII. to XXIV., those for v and T also being plotted in Figs. 45A-H, and a straight line drawn as closely as possible through them. (It will be explained later why, in drawing this line, no notice was taken of the point corresponding to $v = 5$ m. per second.) The values deduced from the graphs for tan β and T_o are also shown in the tables. (In evaluating tan β it must be remembered that the scale adopted for the v-axis is ten times larger than that of the T-axis.) The last columns of the tables contain the values of CG and $\epsilon\phi$ as calculated from those of tan β and T_o. No direct observations were taken of G and ϕ. This is unfortunate, as they would have been illuminating and have afforded some measure of check on the calculated results. At the time of carrying out the experiments, however, the importance of mathematical treatment was not realised as fully as it came to be later, and the desirability of taking the observations in question did not suggest itself.

The Power Consumption Occasioned by the Whipping Action on the Stuff.—It will be seen

from Table XXII. that with the consistency remaining practically unchanged the value of CG increases very rapidly as the furnish (Q) increases. During the various experiments the rate of travel G did not vary appreciably, so that the increase in the value of CG must be due to the factor C increasing in value, probably owing to fresh stuff entering the cells after the latter had passed over the bedplate. For the observations recorded in Table XXII. no hood was fitted to the beater, and when filled with the maximum furnish, the level of the stuff reached to 300 mm. above the crown of the backfall. It is, therefore, easy to understand that the high power consumption may be attributable to the re-entry of stuff into the cells.

In drawing straight lines through the points in the graphs, the point corresponding to the lowest flybar speed is disregarded, and frequently falls considerably above the straight line. This is due to the fact that at a flybar speed of about 5 m. per second the stuff possesses so little centrifugal energy that it is not flung off the roll quickly enough. The roll, therefore, carries it right round, and heavy spitting takes place, thus producing an abnormally high point in the graphs.

For the observations recorded in Table XXIII. a doctor was fitted into the hood of the beater, as shown in Fig. 42, the edge of the doctor being only about 8 mm. distant from the roll. The backfall was made a little higher and the width of the backfall pocket reduced from 50-60 mm. to 10 mm. These alterations produced no appreciable reduction in the power consumed for whipping; but slightly increased the rate of travel, thus reducing the value of the coefficient C.

The experiments with beater No. S5 (see Table XXIV.) were carried out with a consistency of only

5·4 per cent., and showed that the greater part of the power consumption N_R is absorbed in whipping the stuff. This can also be seen from the graph in Fig. 45H, for the line here forms a very large angle with the v-axis. With this beater no difficulty was experienced, owing to the stuff not being flung off the roll properly at low roll speeds.

The Power Consumed in Overcoming Friction in the Stuff.—Table XXII. shows the values for $\epsilon\phi$ found from Figs. 45A-D, at consistencies of about 8 per cent. These values vary between 27 and 33 kg. per square metre. For the moment it is sufficient to note that there is no apparent discrepancy between them and the figures for ϕ shown in Table XXI. which correspond to the wooden boat experiments. When it is remembered that the former values were obtained at roll speeds of 5 to 8 m. per second, while the latter relate to speeds of only a few centimetres a second, it must be agreed that the two sets of results coincide very closely with one another. It was to be expected from the beginning that the coefficient ϵ must be less than 1. The foregoing lends additional probability to the assumption that the internal friction in the stuff is independent of the speed factor.

After the backfall had been altered and a hood fitted as described above, the values found for $\epsilon\phi$ (see Table XXIII. and Figs. 45E-G) became much lower. This was to be expected, owing to there being no eddy motion in the backfall pocket. The clearance between roll and backfall being only 10 mm., the whole of the stuff in the backfall pocket was able to keep pace with the flybars; and instead of there being friction of stuff against stuff (internal friction), the friction now took place between the stuff and the smooth sheet copper surface of the backfall.

Table XXIV. shows that at 5·4 per cent. consistency the friction loss is only small. This also was to be expected, for the internal friction diminishes rapidly as the consistency decreases.

The various points which have just been discussed indicate that it is no easy matter to ensure efficient delivery of the stuff by the roll. An apparently unimportant alteration to the shape of the backfall or an unsuitable roll speed may be sufficient to cause unnecessary waste of power.[1] The speed of the roll must be such that at a minimum of power consumption it will just deliver the quantity of stuff corresponding to the circulation round the trough. If the roll runs too slowly, the centrifugal energy of the stuff will be too small to allow it to be flung over the crown of the backfall. The roll will then commence to spit; and the cells will have to handle the stuff which is carried right round the roll in addition to that which circulates round the trough. This means that they will be required to hold more stuff, and so the power consumed for whipping will be increased.

If the roll speed is too high, the power consumption for whipping will go up (the tangential force T increases) unless the increased centrifugal force causes the roll to spit less. At the highest roll speeds a sudden diminution in the tangential force T has frequently been remarked; and possibly this is due to a reduction in the spitting action.

(If it were true that the laws governing the frictional resistance of ships also apply to beater stuff, it would

[1] The whole of the considerations involved in this connection have been dealt with thoroughly by Kirchner: "Das Papier. IV., Ganzstoffe," pp. 214-234, a study of which the author recommends to those interested in this aspect of the subject.

then be necessary to write equation (24) in the form

$$75N_R = Av^2 + Bv^3,$$

whence

$$T = Av + Bv^2,$$

where A and B are coefficients which are independent of v. This equation represents a series of parabolas which all pass through the origin of the system of co-ordinates. Their axes are parallel to the ordinate axis; and as A and B are always positive the co-ordinates of the vertices of the parabolas will all be negative. If, for example, such a parabola is drawn through one of the experimentally found points in Fig. 45E, the impossibility of making the parabola coincide with the remaining points will at once be realised. (The parabola is shown dotted and marked "*a*.") The limiting parabolas to the above equation are also shown, and it is quite clear that no parabola within these limits can pass through the remaining experimental points.

It is thus established that the internal friction in beater stuff does not obey the same laws as apply to the frictional resistance of liquids.)

CHAPTER V

PARALLEL BEATER BARS. MAXIMUM AND MINIMUM CUTTING ANGLE

ALTHOUGH flybars and bedplate bars exactly parallel to one another have seldom if ever been employed for any length of time, accounts of experience in working them are on record. For example, the author was informed by an experienced beaterman that with a beater roll about 1,200 mm. length on face, no cutting effect can be obtained, unless the bedplate bars are set back at least 50 mm. From another source it was stated that the power consumption of the beater is so great when the bars are parallel that the belt is thrown off. Clayton Beadle and Stevens, in their oft-quoted treatise, say that if roll and bedplate bars are parallel to one another, a maximum drawing-out effect but practically no cutting action will be obtained. At the same time the beater will require more power, as a greater amount of power is needed to draw out the fibres than to cut them. It is not intended to enter here into a criticism of this explanation of the increase in power consumption; but it will be shown that the theory of the adhesion of fibrages to the bar edges explains how it is that a beater with parallel bars takes a great deal of power and only exercises a slight cutting effect.

It will be assumed that in the case of the lawn-mower already referred to, the stationary knives are parallel to the revolving ones, and that the knives

are wrapped round with hemp fibres along their entire length. It will then be impossible without using force to cause one of the revolving knives to pass a stationary knife: resistance to motion will be offered along the entire length of each knife. It will be otherwise, however, if the knives are set at an angle to one another. At any particular moment the stationary knife will then only offer resistance at a single point, and it will be possible to move the mower and overcome this resistance with ease.

Let us now compare this example with the conditions obtaining in the beater.

A beater with roll and bedplate bars set obliquely to one another will absorb practically a constant amount of power over short intervals of time, since the cutting resistance is exerted at a large number of individual points.[1] The smaller the angle between the roll and bedplate bars, the smaller will be the number of points of intersection (see equation (2)), and the greater will be the fluctuation in the number of points of intersection during the course of rotation of the roll bars. Since, when there are few points of intersection, each individual point exerts a greater cutting resistance, the operation of the beater must, therefore, become unsteady. This becomes most noticeable when the bars are exactly parallel, as in that case each bar will offer a resistance to the rotation of the roll along its entire length at the moment of engagement. This resistance may be so great that the momentum of the roll, together with the pull of the belt, will be insufficient to overcome

[1] (*i*) the number of bar intersections, remains practically constant the whole time. Kirchner has shown that the area of contact (F) at various positions of the flybars does not fluctuate much if the bars are set fairly obliquely; and as (*i*) varies with (F) it follows that (*i*) also will not change much.

it: and instead of cutting the fibre the roll will be lifted up over the layer of fibre on the bar edges, and then drop again. This jumping action of the roll will necessarily involve a considerable additional power consumption. It is thus seen that the effects of setting roll and bedplate bars parallel can be fully explained by the fibrage theory.

Having regard to the above it is clear that the cutting angle $\alpha = \alpha_g \pm \alpha_r$ must not be too small. The minimum permissible limit may be taken to be :—

$$\tan \alpha = \frac{50}{1200} = 0{\cdot}042\text{; that is to say, } \alpha > 2\tfrac{1}{2}^\circ.$$[1]

It has been shown previously that the shortening effect of the beating tackle is proportional to the cutting length, and we have

$$L_s = \frac{n}{60} \cdot m_g . m_r \cdot \frac{L}{\cos \alpha_g}.$$

From a first glance at this equation one might be led to suppose that the shortening effect increases with the angle α_g, seeing that $\cos \alpha$ occurs in the denominator. This is, however, not the case, for the term, $m_g \cdot \dfrac{L}{\cos \alpha_g}$, as a whole, represents the aggregate length of the working edges of the bedplate bars. It is this length, and not merely the size of the angle α_g, which determines the cutting effect. If the area of contact (L.B′) of the bedplate is fixed, it is only possible to increase the cutting effect either by using thinner bars or by spacing the bars more closely together.

Either of these measures will result in the aggregate length of the bedplate bars, and therefore also the

[1] The minimum cutting angle should be greater when handling half-stuff or if the roll is light, as the latter then has a greater tendency to jump.

cutting length, being increased. The more effective of the two will probably be to employ thinner bars; for this will also give a higher beating pressure (for the same weight of roll).

It is generally considered that the greater the cutting angle adopted, the greater will be the shortening effect obtained on the stuff.[1] This view is based principally on the extensive cutting effects observed with elbow, zigzag and similar bedplates. The most likely explanation of this fact, however, is that such bedplates usually possess a far greater aggregate length of bar edge than ordinary bedplates with straight bars.[2] If the bars are bent zigzag fashion they will form a larger angle with the flybars, and a thin bar bent in this manner will be just as strong mechanically as a thicker bar set at a smaller angle with the flybars. By employing thinner bars a longer aggregate cutting edge can be embodied in the same area of bedplate, and this is the only reason why such bedplates appear to give a comparatively large cutting effect. Jagenberg, who possessed an instinctive knowledge of the mode of operation of the beater, was also of opinion that the cutting angle is apt to be made excessively large; and that for the purpose of obtaining the most efficient shortening action, the cutting angle should be kept as small as possible.[3]

If the cutting angle is very large it may happen that the flybars will carry away the fibrage on the bedplate bars so that the fibres remain uncut; or if

[1] Cross and Bevan, "Text-Book of Paper Making," pp. 213-214; Clayton Beadle and Stevens, "Theory and Practice of Beating."

[2] Hofmann states that the bars in elbowed bedplates are frequently only 2-4 mm. thick, and also draws attention to the comparatively large cutting surface of zigzag bedplates.

[3] Jagenberg, "Das Hollaendergeschirr," 1894.

the bedplate bars are elbowed the flybars may force the stuff into the elbow angles of the bedplate bars and only a part of the fibres will be cut.

This is demonstrated by the fact that the maximum wear on the flybars takes place at the points which engage with the angular portions of the bedplate bars.[1] Clayton Beadle, therefore, seems somewhat illogical in expressing the view that the maximum cutting effect is obtained with a cutting angle of 45°. It must, on the contrary, be assumed that the cutting effect per metre length of bar has already commenced to decrease at this angle, or as Jagenberg puts it, this extreme angle represents "too much of a good thing." Since there is a minimum limit for the cutting angle which can be usefully employed, it is to be assumed that there is also a maximum limit to it. This upper limit can be determined from a knowledge of the coefficient of friction (f) between the bars and the stuff, as follows :—

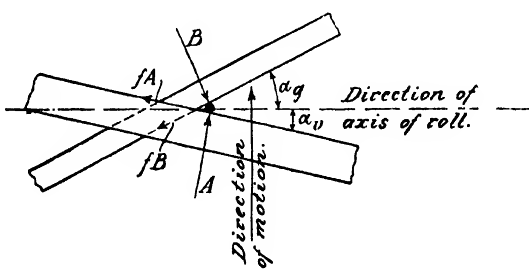


FIG. 46.

Fig. 46 shows a particle of stuff located between a pair of bars engaging with one another. The flybar presses on the particle with a force A, while the bedplate

[1] Clayton Beadle and Stevens, "Theory and Practice of Beating"; Kirchner, "Das Papier. IV., Ganzstoffe," p. 102.

bar exercises a pressure B on the particle. The conditions for equilibrium will then be :—

$$A \cos \alpha_r + fA \sin \alpha_r = B \cos \alpha_g + f \sin \alpha_g,$$

and

$$A \sin \alpha_r + B \sin \alpha_g = fA \cos \alpha_r + fB \cos \alpha_g,$$

whence

$$\tan (\alpha_r + \alpha_g) = \frac{2f}{1-f}.$$

If we put $(\alpha_r + \alpha_g) = \alpha$, which represents the total cutting angle, then the expression can be written in the following way :—

$$\tan \frac{\alpha}{2} = f.$$

Under certain conditions the coefficient of friction (f) can be as much as 0·30 to 0·40. For $f = 0{\cdot}40$, α (the cutting angle) is about 43°.

It thus appears that with a cutting angle of 43° there is already a danger of the fibres being carried away by the roll bar edges instead of being cut. This value must, therefore, be looked upon as the upper limit for the cutting angle, and the latter should, therefore, never be less than 3° or greater than 43°.

PART III

THE CONDITIONS GOVERNING THE FORMATION OF FIBRAGES

THE CONDITIONS GOVERNING THE FORMATION OF FIBRAGES

IN the early part of this book three main equations (10*d*), (11*d*), (12*d*) were evolved to express the output of the beater. The applicability of these equations was then investigated with the aid of comparative beating tests.

In a number of cases it was found that the equations gave results which corresponded closely with those obtained experimentally. In other cases, where the calculated values were not in agreement with the experimental values, the discrepancy was explained by the fact that one of the beaters did not give a sufficiently high rate of travel: the stuff circulated so slowly that insufficient quantities were available for the proper formation of fibrages.

The first essential to obtaining satisfactory output from a beater is, therefore, that the conditions should be favourable for the formation of fibrages, and it is thus not without interest to examine these conditions more closely.

Unfortunately, it is impossible to observe the fibrages visually,[1] for the moment the flybar leaves

[1] *Translator's Note.*—The author informs me that on one occasion he was able actually to observe fibrages. The housing of a Jordan refiner in the mill suddenly fractured. One of the fragments fouled the plug, causing it to jam and stop dead. On removing the top half of the housing, fibrages were seen to be adhering to the plug bars precisely in the manner described in the present work in connection with the theory of the action of beating tackle.—R. M.

the stuff its fibrage is naturally flung off at once. One is, therefore, necessarily confined either to investigating

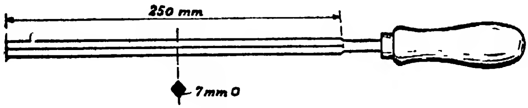


FIG. 47.

analogous phenomena visually, or else dealing with the matter by theoretical methods.

Previous reference has repeatedly been made to the

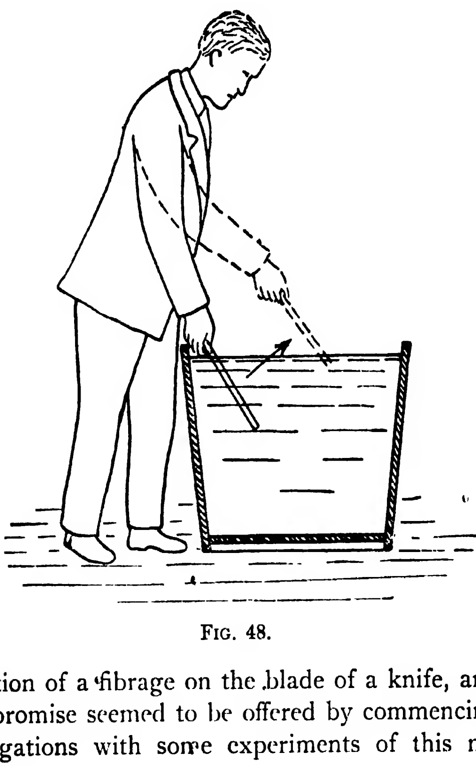


FIG. 48.

formation of a fibrage on the blade of a knife, and the most promise seemed to be offered by commencing the investigations with some experiments of this nature.

A smooth steel rod 250 mm. long, fitted with a handle and of square cross section, was employed (see Fig. 47). The rod was drawn through the stuff (see Fig. 48) with one of its sharp edges kept continuously to the front, thus causing a fibrage to collect on this edge. The size and appearance of the fibrage was found to depend on the speed at which the rod was drawn through the stuff. In order to ensure that every part of the rod should be moving at the same speed, it was accordingly necessary to keep it parallel to its initial position during the whole of its advance through the stuff. Moreover, it was important that its speed should approximate roughly to that of a beater flybar, *i.e.*, say 9 to 10 m. per second. To effect this by hand required a certain amount of practice, which was acquired by repeatedly throwing a stone upwards to a height of 14 to 18 ft., for which purpose it is necessary for the hand to travel at a speed of some 9 to 10 m. per second. Having thus attained the required standard of skill the experiments were commenced.

The first showed that at thin consistencies the fibres readily tend to lie transversely across the edge of the rod in a continuous uniform fibrage. The thicker the consistency the more the fibres tend to deposit irregularly and in bundles, particularly if the rod is not moved sufficiently quickly. *The "carding" action of the edge of the rod, that is to say its tendency to separate the fibres from one another and so enable them to deposit uniformly across the edge, increases very rapidly with the speed at which the rod is moved.* In these experiments the rod was moved through the stuff as described, and the fibrage wiped off each time from the whole 250 mm. length of edge. After repeating this process eight times the total quantity of stuff which had been wiped off was dried and weighed. In this way the weight

of fibrage δ was determined in grams per metre length of rod. The results are shown graphically in Figs. 49 and 50.

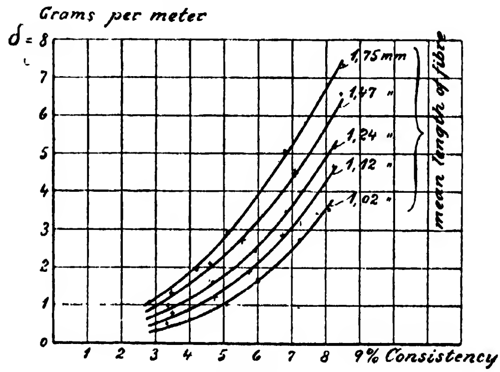


FIG. 49.

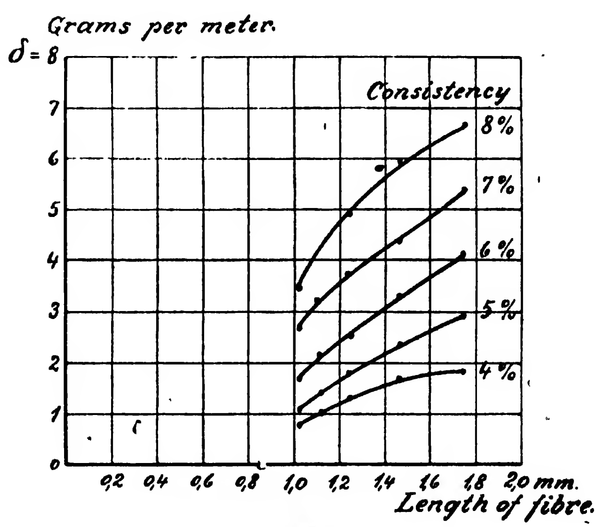


FIG. 50.

Fig. 49 shows the relation between the size of the fibrage and the consistency of the stuff. At high

consistencies the size of the fibrage grows extremely rapidly. If the consistency is thin the fibres are much more readily drawn apart, and therefore slide over one another more easily, so that the edge of the rod will not retain as much fibre. Fig. 50 shows the relation between the size of fibrage and the mean length of fibre in the stuff. As was to be expected, it was found that the mean length of fibre has an important bearing on the size of fibrage, such that with an average length of fibre of about 2 mm. the rod will retain more than twice the quantity of fibres which it retains from stuff of an average length of fibre of 1 mm. As was also to be expected, the experiments showed that the edge of the rod exercises a selective action, in that it chiefly retains the longest fibres. A fibrage taken from stuff of an average length of fibre of 0·87 mm. proved, on microscopic examination, to possess an average length of fibre of 1·01 mm., thus clearly demonstrating the selective action which takes place in favour of the longer fibres.

It is desirable to examine to what extent the results of the rod experiment correspond with practical experience of the behaviour of flybar fibrages.

It is known that the flybar fibrage diminishes in size as the consistency decreases, just as was found in the case of the rod. This is shown by Green's tests (A. B. Green, " Management of the Beater Room," *Paper*, 1917, No. 23). At a thin consistency (3·6 per cent.) Green observed that, under the same roll pressure, the clearance between roll and bedplate was less than at a higher consistency (about 5 per cent.); that is to say, the fibrages were smaller.

The knowledge that the size of the fibrage varies with the consistency of furnish, helps us also to understand why stuff beaten at thick consistencies becomes

"wet." If the size of the fibrage increases so rapidly with the consistency, the treatment of the stuff between the roll and bedplate will be far less harsh as the consistency increases, for the fibrage then acts as a cushion between the bars, and the latter only produce a relatively slight cutting effect.

Practical experience with beaters also shows that the size of the fibrage diminishes as the shortening of the fibre progresses. Thus it is well known that the *cutting action of the roll ceases* after the stuff has been treated for a certain period, and is only resumed when the roll is let down further. (A good illustration of this may be found in the curves published by Clayton Beadle, "Chapters on Papermaking," v., p. 151.) The explanation is that after beating for some time, the fibrage becomes so attenuated that no more cutting can take place until the clearance between roll and bedplate has been reduced accordingly.

Moreover, the micro-measurements carried out by W. Gruenewald (*Zellstoff und Papier*, 1921, No. 1, p. 23) indicate clearly that the edges of the flybars exercise a selective action similar to that of the edge of the square rod. Experiments by the same authority show that the shortening action of the beating tackle principally takes effect on the longer fibres, the short fibres slipping through untouched. This is precisely what one would expect of the selective action of the flybar.

It will be appreciated from the foregoing that practical experience agrees in all essentials with what one would expect according to the theory of the fibrage and the rod experiments. This certainly affords a good support for the theory.

We shall now proceed to examine from a theoretical standpoint the conditions which obtain when the stuff

enters the cells in the roll. A knowledge of these conditions renders it possible to design a beater which offers the most favourable conditions for the formation of fibrages.

As the stuff approaches the roll it flows in an approximately horizontal direction. Fig. 51 illustrates a beater roll and shows on a greatly exaggerated scale the dimensions which govern the entry of the stuff into the

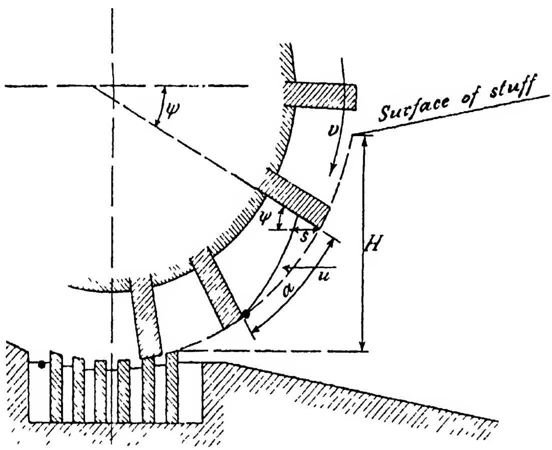


FIG. 51.

cells. The horizontal velocity of approach is denoted by u (mm. per second); and will probably be less nearer the top surface of the stuff than lower down, for there are two factors which have to be considered. On the one hand, the stuff possesses a motion caused by the anterior masses pressing continuously from the backfall towards the approach to the roll: the velocity due to this is probably the same at the top as it is at the bottom of the stuff. On the other hand, the hydrostatic pressure of

the upper layers of stuff on the lower layers tends to impart to the latter an increased velocity of approach. It has already been pointed out that stuff is certainly not a liquid in the physical sense, since a force of definite magnitude is required to slide one layer over another. At a sufficient depth beneath the surface, however, the weight of the upper layers may produce such a high pressure as to outweigh the effect of internal friction; in which case the stuff will flow into the cells in a manner similar to that, for example, of a viscous fluid. It is not proposed to differentiate here between these two component factors of the motion of the stuff, our immediate object being to determine merely the general characteristics of this motion. It will, therefore, be assumed that u represents the mean horizontal velocity with which the stuff enters the roll cells.

This velocity can easily be found if the amount of stuff (G) transported per second by the roll has been measured by the method indicated in Part II., Chapter IV. Instead of denoting this by G kilograms per second, we will now express it as V litres per second. For the moment it will be assumed that the flybars possess no thickness and that the width of the approach channel for the stuff is the same as the width of the roll (L). The depth of stuff in front of the roll may be denoted by H (metres). We then have

$$V = u.L.H.$$

In actual fact, of course, the flybars possess a definite thickness (s_v) and the effect of this thickness is to make the effective height of the channel of approach somewhat less than H, the depth of the stuff. The mean pitch of the flybars is given by $\frac{\pi D}{m_v}$ irrespective of whether they are spaced equally or not; and is denoted by

d_v. The true value of u is, therefore, given by the equation :—

$$V = u.L.H\frac{d_v - s_v}{d_v},$$

whence

$$u = \frac{V.d_v}{L.H(d_v - s_v)}.$$

Let us now consider a cell the bars of which are spaced any given distance a (in metres) apart. From the moment at which a flybar leaves any given position until the moment at which the next flybar occupies this same position, an interval of time $\frac{a}{v}$ (in seconds) elapses, v being the speed of the flybars. During this time the stuff moving at a velocity of u millimetres per second will travel through a distance of s millimetres, where

$$s = \frac{a}{v}.$$

Inserting the value found for u, we have

$$s = \frac{a}{v} \cdot \frac{Vd_v}{L.H(d_v - s_v)}.$$

As the flybar progresses through the stuff its action to some extent resembles that of the cutting edge of a planer; and it, so to speak, planes off a "shaving" of stuff. The thickness of the shaving is approximately $s \cos \psi$. The equation for s shows that this thickness is directly proportional to the interval a between the bars. The length of the shaving is equal to the distance between the surface of the stuff and the first bedplate bar, and is, therefore, the same for all the flybars. It will thus be seen that the amount of stuff which enters a roll cell must be directly proportional to the interval

between the flybars which form that cell. If it be imagined that the stuff in each cell is distributed in a layer of uniform thickness (see Fig. 15), then in the same beater roll there will be an equal depth or thickness of stuff in every cell irrespective of whether the cell is wide or narrow, *i.e.*, irrespective of the spacing of the flybars. The capacity of a cell for transporting stuff is, therefore, in theory directly proportional to the interval between the two flybars which bound it. Equation (16) for the depth of cell filling which was evolved in Part I., Chapter V., without regard to the pitch of the flybars, is, therefore, theoretically correct irrespective of whether the flybars are spaced equally or in clumps.

Experience in practice, however, does not entirely corroborate this theory. Wide cells will transport relatively more stuff than narrow cells, particularly in cases where the bars are arranged on the roll in clumps. Kirchner has demonstrated this with the aid of two examples described in the *Wochenblatt fuer Papierfabrikation*, 1919, p. 191. In the first example a roll with bars spaced 64·5—21·5—21·5 mm. was replaced by a roll with bars spaced 74·5—12—12 mm. apart; and at the same time the thickness of the flybars was increased from 7 mm. to 10 mm. The total number of flybars remained unchanged. It might have been expected that the transporting capacity of the roll would thus have been diminished, because the sum of the intervals between the flybars in each clump had been reduced from 107·5 mm. to 98·5 mm., and because the individual intervals are theoretically of no consequence. Nevertheless, it was found after the change had been made that the travel of the stuff in the beater was greatly improved. It must be concluded from this that the transporting capacity of the wide cells

was increased to a comparatively greater extent than that of the narrow cells was diminished.

In the second of Kirchner's examples, the spacing of the flybars was changed from 50—17—17 mm. to 25—25—25 mm., and the transporting capacity of the roll was then found to be considerably diminished. It is thus seen again that the wide cell fills to a greater extent than the theory would lead one to anticipate. It may be imagined that the stuff being inert requires a certain length of time to set itself in motion after a flybar has passed; and consequently will not penetrate as deeply into a narrow cell as it otherwise might.

It has already been seen that the primary essential for obtaining efficient beating is that sufficiently large fibrages shall be deposited on the edges of the flybars. A necessary condition to the deposit of such a fibrage is, however, that, during its passage through the stuff, the edge of the flybar must encounter at least as many fibres as it is expected to retain. It has furthermore been seen that the edge of a flybar following a wide cell encounters more stuff than one following a narrow cell. It therefore follows that if the circulation is such as to cause a fibrage of the correct size to be deposited on a flybar following a wide cell, then a flybar following a narrow cell will take up too small a fibrage. Conversely, if the circulation is so rapid as to provide adequate fibrages for the bars following narrow cells, then a great deal of stuff will be transported unnecessarily in the wide cells. This superfluous transport requires power which represents so much loss, and the beating, therefore, loses in efficiency. Arranging the flybars in clumps must, therefore, be regarded as uneconomical. The only advantage of rapid circulation is that due to the proper formation of fibrages, which thereby accrues.

It will be assumed that the fibrage deposited on the edge of the square rod is of the maximum size possible under the given conditions (consistency, mean length of fibre). The size of this fibrage is denoted by δ reckoned in grams of air-dry fibre per metre length of edge. The consistency of the stuff in the beater is given by ρ as before in kilos of fibre per litre of stuff. The interval between two consecutive flybars has been taken as (a), and the depth to which the cells are filled as (x). A cell 1 metre long will then contain $a.x$ litres of stuff, or 1,000 $\rho.a.x$ grams of fibre.

The most advantageous conditions possible would be produced if all the available fibres were retained by the edges of the flybars so that only fibre-free water actually entered the cells. If 1,000 $\rho.a.x$, which represents the cell content, is less than δ (the largest possible fibrage), then it will clearly be impossible for the beater in question to operate with the largest possible fibrage; and the beater will, therefore, not be working efficiently. In all probability it is practically impossible for all the fibres to be retained on the bar edges; and only a certain percentage of the fibres entering the cells will collect on these edges. It therefore follows that for efficient operation of the beater, 1,000 $\rho.a.x$ must be greater than δ. How much greater can only be determined from comparative observations on the working of good and bad beaters.

A number of beater tests will now be taken and the amount of fibre available for the formation of fibrages (1,000 $\rho.a.x$) will be calculated and then compared with the corresponding value of δ (for example for 1·75 mm. length of fibre—see Fig. 49). If it is found that a satisfactory beating output is obtained when the value of 1,000 ρax is so-and-so many times greater than the value of δ, this will then afford some support for the

assumption that the fibrages measured in the rod experiments correspond exactly with those deposited on the edges of the beater roll flybars.

(*a*) For the first example reference will be made to the tests described in Part I., Chapter VI. (Tests No. 2). In the test with the stuff propeller, $\rho = 0{\cdot}05$, the depth (x) to which the cells were filled = 11 mm. and $a = 0{\cdot}0354$ m. The quantity of fibre available for forming fibrages was, therefore, 19 grams per metre, or roughly 7.δ. In the test without a propeller, $\rho = 0{\cdot}05$, $x = 2$ mm., and the amount of fibre available for fibrage formation became reduced to 3·5 grams per metre, or roughly 1·2δ. The beating output with the propeller was far greater than that in the test without the propeller.

(*b*) Test No. 13 described in the same chapter was carried out at a consistency of $\rho = 0{\cdot}069$. The cells were filled to a depth $x = 11{\cdot}8$ mm., and the interval (a) between the flybars was 0·042 m. The amount of fibre available for the formation of fibrages was 35 grams per metre, or roughly 7δ. In the second test (No. 12) the output of the beater was only about half as great, $\rho = 0{\cdot}071$, $x = 3{\cdot}7$ mm., and $a = 0{\cdot}039$, which gives only 10 grams per metre of available fibre, or roughly 1·8δ.

(*c*) The experiments described under section 4 of the same chapter were carried out on bast fibres and at a comparatively thin consistency. The one beater (No. 14) worked with a consistency of $\rho = 0{\cdot}041$, $x = 2{\cdot}4$ mm., $a = 0{\cdot}048$ m.; the quantity of fibre available for fibrage formation was 5 grams per metre or approximately 2·5δ. In beater No. 15 the consistency was $\rho = 0{\cdot}031$, $x = 2{\cdot}0$ mm., $a = 0{\cdot}030$ m.; while the quantity of fibre available for fibrage formation was 1·9 grams per metre, or roughly 1·6δ. The specific output of this beater was much lower than that of beater No. 14.

(*d*) In Part I., Chapter V., section *b*, an example is described which shows that the output is materially diminished by increasing the consistency. The figures given are: $\rho = 0{\cdot}07$, and $x = 12{\cdot}5$ mm. The spacing of the fly-bars is 64—21·5—21·5 mm. From this it will be found that the quantity of stuff available for fibrage formation is 56 grams per metre for the bars following the wide cells, and 19 grams per metre for those following the narrow cells. These values correspond to 11δ and 4δ respectively. The consistency was then increased to $\rho = 0{\cdot}076$, giving a depth of cell filling of only 2·7 mm., and lengthening the beating time by 50 per cent. In this case the amounts of stuff available for fibrage formation were 13 grams and 4·5 grams per metre length of bar following the wide and narrow cells respectively, these amounts corresponding respectively to $2{\cdot}2\delta$ and $0{\cdot}75\delta$.

On then increasing the consistency to 0·08 (8 per cent.) the rate of travel of the stuff became so slow that the depth of cell filling was reduced to $x = 1{\cdot}25$ mm. At this stage it was practically impossible to complete the beating process as the stuff became discoloured grey before it was finished beaten. The amounts of stuff available for fibrage formation were 6·4 and 2·1 grams per metre respectively, corresponding to approximately $0{\cdot}8\delta$ and $0{\cdot}25\delta$ respectively.

(*e*) According to Kirchner, Arnold Rehn in his well-known experiments worked with a circulation of 95 litres per second. This circulation corresponded to a depth of cell filling of 10 mm. The experiments were carried out at 5 to 6 per cent. consistency, $a = 0{\cdot}035$ m. The amount of stuff available for fibrage formation was, therefore, 17·5 to 21 grams per metre, or about 5δ.

Looking at the results of all the experiments enumerated above, it will be seen that the working of the beater becomes comparatively unsatisfactory, and its output

decreases considerably as soon as the amount of stuff available for fibrage formation becomes less than $2\frac{1}{2}$ to 3 times as great as the fibrage formed on the square rod from stuff of an average length of fibre of 1·75 mm. It is noteworthy that whereas at 4 per cent. consistency 5 grams of available fibre per metre were found to be ample (Experiment *c*), this amount of fibre was quite inadequate in the cases where higher consistencies were employed. Owing to the rapid increase in the size of the fibrage as the consistency increases a far greater "available" quantity of stuff is required: that is to say, for thick consistencies a much higher rate of travel of the stuff is required than for thin consistencies.

As a rule the speed of circulation in the beater is sufficiently high to cause the cells to be filled to the depth required for the formation of fibrages. Sometimes it has to be assisted by one or other form of propeller. In many beaters, however, especially old-fashioned types with very little slope to the floor of the trough, the speed of circulation is too slow to secure adequate fibrage formation. If on occasion such beaters nevertheless give a satisfactory output, this must be attributed to the spitting of the roll. It is naturally a matter of indifference, as far as the mere filling of the cells and the formation of fibrages is concerned, whether the stuff necessary for these purposes is supplied from the normal flow round the trough or whether it is carried right round over the top of the roll.

The author has found in the case of an old beater of this kind working on a consistency of 4 per cent., $a = 41$ mm., that the depth of cell filling due to normal circulation round the trough was only 0·5 mm.; while the depth due to spitting was 1·5 mm. It was only when this amount of spitting took place that the still meagre quantity of 4 grams of stuff per metre became available for fibrage formation.

It will thus be realised that under certain conditions spitting may be essential to obtaining output from a beater. Some means of measuring spitting may,

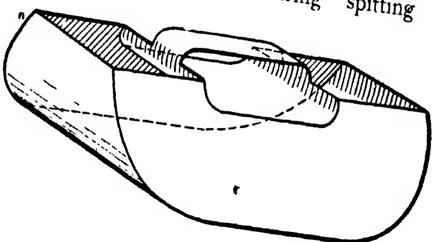


FIG. 52.

therefore, appear desirable. A suitable device has been constructed and is illustrated in Fig. 52. The method of employing it is indicated in Fig. 53.

The amount of stuff discharged per second per 100

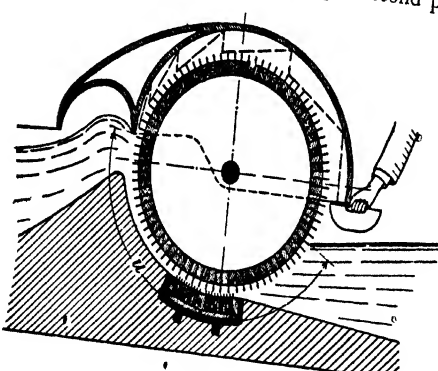


FIG. 53.

mm. width of roll is measured with the aid of a stop watch. The measurement is repeated at various positions across the width of the roll; and in this way a mean value is obtained for the amount of stuff which the roll carries round for every 100 mm. of its width.

SUMMARY

THE most important points embodied in the foregoing treatise may be briefly summarised as follows :—

Mode of Operation.—The action of the beater may be regarded as a two-fold one, comprising a cutting action between the edges of the flybars and the bedplate bars which produces a shortening of the fibres ; and a wet beating action caused by pressure and abrasion between the working surfaces of the flybars and bedplate bars. The extent to which the fibre is shortened can be determined by microscopic measurement in the manner described by Clayton Beadle. The wetness of the stuff can easily be determined with the aid of the Schopper-Riegler beating tester.

Thus the effect on the stuff of beating can be expressed numerically ; and by combining the numerical expressions for the shortening and wetting effects it is possible to characterise any given beating operation.

In addition to the foregoing, the action of the bar edges (partly assisted by the whipping of the flybars on the stuff) tends to draw out, brush, or card the stuff, thus promoting the disintegration of the fibre bundles.

The wetness of stuff may be defined as its capacity for retaining water and, therefore, only parting with it slowly on the wire of the papermaking machine. It is to be presumed that the softening effect produced on the fibres by compression between the bar surfaces has a considerable influence on the readiness with which the stuff parts with its water on the machine wire, that

is to say, on the wetness of the stuff. As its water drains away, wet stuff will form a more compact and thinner layer than free stuff. The numerous tiny drainage channels will thus become more constricted and so will retard the drainage of the water. The softness or plasticity of the fibres, therefore, tends indirectly in two ways to improve the strength of the sheet. Firstly, wet beaten fibres felt better than free stiff fibres. Secondly, the reluctance of wet stuff to part with its water allows more time for the shake on the wire to take effect and felt the sheet.

Wetness is also governed by the extent to which water is absorbed into the hollow interior and walls of the cells (hydration). The crushing and fibrillation of the stuff contribute to producing wetness in so far as fibrillæ and small fragments of fibre tend to fill up the interstices or drainage channels in the sheet and so retard the drainage of water.

The new theory of the action of the beating tackle lays down that the stuff is actually beaten while lying across the edges of the flybars and bedplate bars, in the same way as it will lie across the edge of a knife blade if the latter is drawn through the stuff (fibrages). This theory has been confirmed by observations carried out on eighteen beaters in one mill. In these beaters a fairly coarse china clay was employed and considerable wear took place on the front surfaces of the beater bars. This wear, however, only commenced about 2 mm. above the working edge of each bar, the edges themselves having apparently been protected by the fibrages. Stuff eddies or rolls of stuff are formed in the cells between the flybars and probably cause fibrages to be deposited on the edges of the bedplate bars.

The new mode of treatment of the beating operation facilitates explanation of a considerable number of

observations, such, for instance, as the decrease in output of the beater if the circulation is too slow or if the bars are set too closely together. Under these circumstances only a small quantity of stuff is able to enter the cells and the formation of adequate fibrages on the bar edges is thus hindered. This accounts for the great importance which is often attached—particularly in Germany—to rapid circulation.

It has also been established that when working with thick consistencies, good circulation is essential in order to secure a large output from the beater. Arising out of this, Professor Pfarr has developed the untenable theory that output is proportional to rate of circulation.

It is a matter of general experience that the output of a beater diminishes unduly if the flybars are spaced too closely together.

Unless one assumes that the stuff is carried forward by the bar edges it is difficult to understand properly how it can manage to penetrate between the working surfaces of the bars. Friction experiments carried out with stuff sandwiched between a sliding metal block and stationary smooth and fluted surfaces tend to bear out the assumption that the stuff is carried forward by the edges of the bars.

Output.—Let D, L, and P represent respectively the diameter, width, and pressure of the roll, m_g and m_v represent the number of bedplate bars and flybars respectively, and s_g and s_v their respective thicknesses. n is the number of revolutions per minute of the roll. The units are the kilogram and metre. If L_s is the cutting length per second of the beater, then

$$L_s = m_g . m_v . L . \frac{n}{60}.$$

It has been shown that the shortening effect of the beating tackle is proportional to the cutting length L_s

and that the wet beating effect is proportional to $L_s(s_g + s_v)$ provided that the consistencies and pressures per centimetre of bar edge are the same in any two cases under comparison.

If q is the production of the beater in kilograms of stuff per hour (*i.e.*, the furnish divided by the beating time), λ_1 is the original mean length of fibre and $\frac{\lambda_1}{m}$ the mean length of fibre at the conclusion of beating, then the following will be the equation for the cutting effect :—

$$q.\frac{m-1}{\lambda_1} = c.L_s.$$

Further, if $(\omega_2 - \omega_1)$ represents the increase in the wetness of the stuff caused by treating it between the bar surfaces, then the following will be the equation for the wet beating effect :—

$$q(\omega_2 - \omega_1) = c'L_s(s_g + s_v).$$

The terms c and c' are coefficients which depend on the consistency, beating pressure, and the initial and final state of the stuff ; but not on the dimensions of the beating tackle.

Eliminating q from the last two equations, we obtain the equation for the character of the beating process, viz. : —

$$\frac{\lambda_1(\omega_2 - \omega_1)}{m-1} = \frac{c'}{c}(s_g + s_v).$$

In order to secure adequate fibrage formation on the bar edges, particularly when working with high consistencies, it is important that the cells should be sufficiently filled to enable the stuff contained in them to eddy energetically. The speed of circulation in the beater must, therefore, not fall below a certain limit. With thin consistencies it appears that the quantity of stuff required in the cells is less than at high consistencies.

The roll pressure exercises some influence on the rapidity with which a given shortening effect or a given degree of wetness can be attained. As the working surfaces of the bars are not completely covered with stuff, but only carry stuff along and in the vicinity of their edges, it is not a question of the so-called specific pressure, as calculated according to Jagenberg's "crushing" formula. The determining factor is the edge pressure per centimetre length of bar edge, which should be found from the following equation :—

$$p_l = \frac{P\pi D}{100 m_g m_v (s_g + s_v) L}.$$

Experiments have been carried out with a number of fibrous raw materials for the purpose of determining the influence of pressure and consistency on the rapidity with which a given shortening effect or a given wetting effect can be obtained. The results of these experiments are illustrated by means of curves (Figs. 13, 14*a*, and 18) in which the ordinates represent the numbers of kilograms of stuff beaten per hour to the given final condition, per metre cutting length per second, or per square metre beating surface per second.

The expression "beating time" is often taken to mean the period of time required to shorten the fibres in a furnish to the required extent, the beating action being judged according to the degree of wetness of the beaten stuff. The cutting length L_s, therefore, governs the quantitative output (production), while the qualitative output (character of the stuff) depends on the size of $(s_g + s_v)$, *i.e.*, on the thickness of the bars.

Since a certain minimum spacing must necessarily be maintained between the flybars, it follows that the output of the beater (the cutting length per second) will increase with the diameter and width of the roll.

The output will also increase with the number of bedplate bars, and with the circumferential speed of the roll. The two latter dimensions, however, cannot be selected entirely at will. No advantage is to be gained by increasing the number of bedplate bars beyond a certain limit, and the speed of the roll must also be kept within bounds in order to prevent the centrifugal action from becoming detrimental. Further investigations in this connection must be reserved for a future occasion.

Power Consumption.—If the beater is individual motor driven it is possible to determine the power required for actual beating (power consumption of the beating tackle) as well as the power consumed for rotating the roll in the stuff. Tests of this description, as well as no-load tests, have been carried out and gave the following results :—

The no-load power consumption is principally absorbed in bearing friction. An example is given showing how the bearing friction can be calculated for different roll pressures.

The power consumption of the beating tackle (that is to say, the power consumed in beating the stuff between the bars) is made up of

(1) That absorbed in cutting the fibres, and
(2) That absorbed by the tearing action between the surfaces of the bars.

A mathematical expression has been found to illustrate the effect of these two factors on the aggregate power consumption of the beater. Hitherto, in calculations relating to the power consumption of the beating tackle the so-called beating coefficient has been employed. In the present work, instead of calculating with the beating coefficient, the specific power consump-

tion per square decimetre of beating surface per second has been adopted, as this renders the results more readily comprehensible. The specific power consumption is denoted by μ and $\bar{\mu} = \bar{\mu} \times p_k$. Further tests were carried out to determine the effect of the speed of the flybars and of the edge pressure on the power consumption for beating. The results of this work are depicted graphically in Figs. 25A-E; and an attempt is made to explain the peculiar shape of the curves shown.

Special tests have been devoted to measuring the power absorbed in tearing the stuff between the surfaces of the bars; and incidentally an explanation has been found for the apparent discrepancy between Kirchner's measurements of beating coefficients and Haussner's measurements of the coefficient of friction of stuff.

It appears from these investigations that the working of the stuff between the surfaces of the bars, as Kirchner correctly states, is not a rubbing but a tearing operation. This tearing only occurs if the stuff is in a more or less disintegrated or loosely felted condition: it does not occur if the stuff is treated in the beater in sheet or board form, even if unsized; a condition similar to that of well-broken or half-beaten stuff is essential, such as that of unsized, softened, crêped serviette paper, or hand-made, lightly couched sheets of waterleaf. The power required for the tearing action has been measured in numerous instances and under the most widely varying conditions, so as to provide an explanation of all the factors which can affect this part of the power consumption of the beater. Finally, a comparison is drawn between the curve for the specific power consumption, and that for the power absorbed in tearing at various pressures.

Further discussion and experiments are devoted to

the internal friction in beater stuff; and the conclusion is drawn that in all probability special laws of friction apply, which differ from those governing the behaviour of solids and liquids. The following law for the friction of beater stuff suggests itself as the outcome of experiments carried out with the aid of specially designed apparatus :—

The resistance to sliding motion along any cleavage plane in the stuff is directly proportional to the area of that plane, and is independent of the pressure on the plane or of the velocity of the motion.

The power required to rotate the roll in the stuff is partly absorbed by the whipping of the flybars on the stuff as it enters the cells, and partly in overcoming the friction between the stuff which revolves with the roll and that which remains more or less stationary in the trough. The former item of power is proportional to the square of the speed of the flybars, while the latter is in direct proportion to the speed of the flybars. It is thus possible to determine each of these two components of the power consumption separately, and this has been done in a number of examples.

The new theory—namely, that the stuff is beaten while in the form of fibrages adhering to the bar edges—is applied to the case in which the flybars are set parallel to the bedplate bars; and affords an explanation of certain peculiarities which are known to arise under these conditions, such as high power consumption and diminished cutting effect.

The size of the cutting angle between flybars and bedplate bars is discussed. It is shown that in order to maintain smooth running and an efficient cutting action, the cutting angle should not be less than 3°. On the other hand, it must not exceed 43°, as otherwise the flybars will tend to push away the stuff instead of

cutting it. It is frequently assumed that the cutting effect increases as the cutting angle becomes larger. No proof could be found for this. Providing only that the cutting angle is not less than 3° there is no reason to believe that the cutting effect increases with the cutting angle.

Conditions for the Formation of Fibrages.—The fibrage formed on the blade of a knife when the latter is drawn through the stuff serves as an example of the fibrage formed on the edges of the flybars. The existence of a definite relationship between the size of the fibrage and the consistency of the stuff and its mean length of fibre has been established experimentally. These experiments confirm that the fibrage deposited on the blade of a knife is comparable with the fibrage formed on the beater flybar. If the circulation in the beater is too slow, the roll will not receive sufficient stuff to enable adequate fibrages to be formed on the edges of the flybars, and the desired beating effect will not be attained. The accuracy of this conclusion is substantiated by careful examination of the results of numerous beater trials, many of which were carried out by the author, the remainder having been published from time to time in the technical press.

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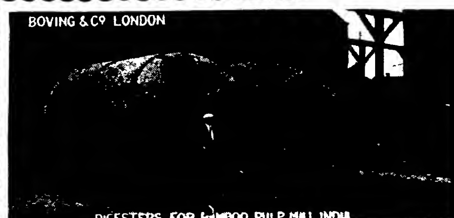

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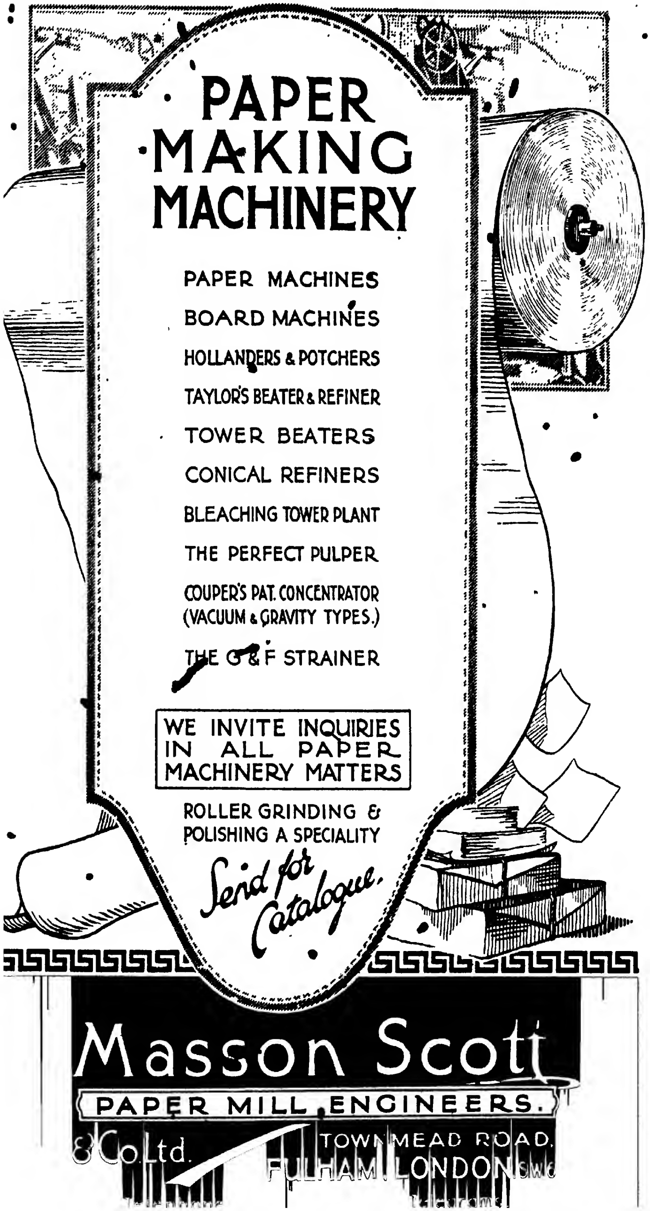

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